NORWEGIAN METHODS OF WEATHER ANALYSIS

By

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1. The Norwegian meteorological institutes are recognized for their methods of analysis based on air masses and fronts. Their fundamentals have been known for many years. Recently, new studies by the Bergen and Oslo institutes have led to important changes in methods, and improved results. Analysis technique differs from that formerly used. In most cases the differences have forecasting significance. To what extent is best seen by comparison of recent maps with those drawn by earlier methods. Examples have been prepared by the Aerology Section, Bureau of Aeronautics, to bring out the chief differences. These are attached to the U.S. maps which are a part of this report. The maps were analyzed during the Bergen Oslo survey.

2. Because of their naval interest, the methods of the Bergen-Oslo school were studied in detail. This interest has at least two aspects. First, the methods represent the most promising system for obtaining advance information of those weather elements which have importance in strategy and tactics - for instance, visibility, cloud ceiling, fog, and winds as related to scouting, gunfire, spotting, aircraft and submarine operations. They thus make it possible for forecasts to go beyond gale and storm warnings and give information of these special elements which are important for modern fleets. Second, these special methods represent advance in forecasting based on few reports at sea, or in extreme cases on only one report. This is the situation during radio silence when forecasts are of most value in the plans of the fleet. It is not implied that at the present stage it is possible to forecast weather satisfactorily from one or two reports only. The latest methods of analysis do, however, improve the forecasts made under such circumstances and appear to offer a logical basis for further development of such forecasts.

3. The Bergen-Oslo methods are based on studies to explain features in the behavior of cyclones and anticyclones previously left unexplained in analysis. The results have been due in part to the dense reporting network and the frequent maps available in the European services. These provided an approximation to space and time differentials by which weather processes could be closely followed. Such studies have been difficult or impossible with the less numerous and less frequent reports available in America. However, with

the principles derived from the detailed studies in Europe, the methods can be applied in analysis of reports and weather maps here. The U. S. maps for February 3 to 5, 1931 illustrate. With the principles available here at that time, a forecaster expected the cold front of the Gulf storm to pass eastward into the Atlantic followed by good flying off the coast a few hours after clearing had set in over the southeastern states, Gulf Stream influences excepted. The Bergen analysis however showed that development of a loop occlusion was to be expected followed by renewal of line squall conditions along the Carolina coasts. That the analysis and its forecast of cloud ceiling, thunderstorms and wind were correct is verified by observations aboard the U.S.S. Los Angeles enroute southward over those waters at that time.

4. For purposes of this report, methods of the Bergen-Oslo institute were surveyed as follows. (1) One hundred twenty American weather situations were analyzed in discussion with Prof. Bjerknes, Drs. Bergeron and Petterssen. (2) Daily analysis of the six hourly European maps were studied during the entire period of survey, the methods, discussions, forecast conferences and occasional lectures noted. The daily 1400 chart was analyzed and compared with the official analysis. (3) Studies were made of unpublished papers and research in progress. Principal features of these are embodied in the report. The references and enclosures show the important published papers. The Bergen-Oslo methods of analysis are reported in detail in paragraphs 11 to 140.

5. In connection with the survey, considerable information was obtained about the organization, administration, personnel, equipment, etc. of the meteorological and aerological services. The subjects which appear to be of sufficient interest to report are given briefly in paragraphs 6 to 8.

6. The Norwegian service is administered through three forecast centers, Oslo, Bergen and Tromsoe, all loosely centralized under Oslo. There are fifty five forecast districts, thus permitting fine local distinctions in forecasts. The density of the reporting network approximates that of the regular W. B. reporting stations in our Middle Atlantic States. Reports are collected four to six times daily by telephone, telegraph and radio, the national system fitting into the European International Weather broadcast system as described in reports of International radio and meteorological commissions. The code provides for much detail in reporting observations. The detailed observations are important in analysis and adoption of a similar code or its equivalent for reports

within the Fleet probably is a necessary step to full utilization of the methods reported herein.

7. Aerological equipment and methods need no detailed description. Points of interest are: The meteorograph used is the Jaumotte type (Brussels, Bergium, mfgr.) which provides a streamlined chamber strapped to an airplane strut midway between the wings. The airflow through the chamber is regulated to avoid vibration and interference with accurate registration. The meteorograph proper is suspended within the chamber. It is designed with special attention to balancing and compensation against vibration, back lash, etc. The meteorograph pens are fitted for marking the record at significant places in flight, such as bases of clouds, the marking device being operated electrically from the cockpit. Smoked charts are used with base line pen to furnish the reference line. Calibration methods are thorough but not unusual. A celluloid scale, prepared for each instrument serves as a quick means for obtaining desired values from the chart without drawing time arcs on the chart. The Jaumotte instrument is one of the best designed meteorographs on the market, and the features just referred to could advantageously be adopted to our needs. The theodolite in common use is a Fuess (Berlin mfgr.) recording theodolite using circular chart and marking needle actuated by push rod and elevation angle mechanism. It permits greater accuracy when only one observer is available for pilot balloon ascents, but is not recommended for service purposes. A pilot balloon slide rule incorporating rate of ascent as well as linear and cotangent scales eliminates the separate computation of altitude but is too long for convenience in shipboard use. A four cup portable anemometer (Wihelm Morell, Leipzig, mfgr.) operating on the speedometer principle gives direct readings of velocity and is used for calibration of field station anemometers in Norway. This type is superior in accuracy and convenience to the fan type integrating instrument used here with stop watch to obtain wind velocities on C V deck. No outstanding features were observed in other items of equipment.

8. Computation of aerological data is performed by combined use of the adiabatic chart and the Bjerknes Tables No. 9-M. The procedure is analogous to although not identical with that in use in the Navy. Thermodynamic characteristics of the air mass are examined by plotting the data on the Emagram, a form of energy diagram. Refsdal has developed still another diagram (Geogram) which permits estimation of energy from an area on the diagram in form more easily obtained with usual aerological data than on the tephigram. The method is still experimental and is not published. A description and the underlying equations are available in the survey notes. An improved cloud atlas has been distributed. Its use promotes uniformity in cloud reports, important in analysis. See "International Cloud Atlas".

9. and 10. Omitted.

11. ANALYSIS. The object of analysis is to ascertain the characteristics and physical inter-relations of each different air mass on the weather map and to determine the location and structure of each important front. With these facts known, there is a rational basis for the weather forecast. The analysis deals with air mass and fronts more or less simultaneously, sometimes one, sometimes the other being foremost. Relative importance depends upon the given weather distribution, region, etc. For clarity, the two are described separately.

12. REPRESENTATIVE REPORTS. It is essential that analysis be based upon data which are representative of true air conditions. Otherwise incorrect conclusions and poor analysis are unavoidable. In practice, surface weather reports cannot be wholly representative. Expert interpretation corrects the discrepancies. Knowledge of topography, or type of instruments, character of instrument exposure on each ship or station and even the qualifications of the observer are in some cases indispensable for this purpose. For example, the wind reports from valley stations are misleading, the temperatures reported by ships on sunny days are often too high. With these influences in mind, the forecaster can apply probable corrections in some cases, or can disregard reports which are not representative. "Stations" most likely to get observations representative of general air conditions are those situated on small flat islands, or on mountain tops, or ships. Observations from these are less likely to be influenced by local surface phenomena which mask the true conditions of the overlying general air mass. Moreover, observations are more representative in certain portions of cyclones and anticyclones than in other portions. Exposures and other local effects being the same, reports are most representative when wind is strong enough to prevent large temperature inversions on the ground, and sky is overcast thus reducing loss of heat by radiation, gain by insolation, etc, Contrary to the impression in Germany, etc., the Norwegian school does not suppose that surface reports can always be representative of overlying air layers. The claim is simply that the important air masses can be identified in nearly all cases by proper interpretation of surface reports from suitably exposed stations, especially if supplemented by the aerological observations now available.

13. BASIC IDEAS. Certain principles are so fundamental in present methods of front analysis that they are summarized here. With reference to precipitation forms - drizzle, rain, and showers are carefully distinguished from one another. Each of these requires a different and distinct type of atmospheric structure. Similarly, forms of snow, sleet, hail, etc., are distinguished. The observer recognizes drizzle by its very small and relatively

numerous droplets; rain (including very light rain) by its steady fall and its larger and decidedly less numerous drops; and a shower by its relatively large drops and brief duration. The forecaster, with these forms expressed in symbols on the map, identifies by the drizzle report, a warm, moist air mass with stable lower layers. By the rain report, he recognizes an alto-stratus system and a warm front surface, and by the shower report, an unstable air mass indicative of a cold front or polar air. These cases are illustrative. With reference to clouds - alto-stratus are carefully distinguished from strato-cumulus. The former indicates a warm front surface, the latter, a cold air mass. Alto-stratus, alto-cumulus and strato-cumulus are frequently confused by observers. Nimbus and stratus, commonly found near the inner edge of a warm front rain system, are carefully distinguished from cumuli-nimbus, a cold front cloud form. Nimbus, so named because it was originally thought to be the source of rain, is structurally similar to stratus and is so classed by the Norwegian school. This confusion has led to proposals to change the name of alto-stratus to nimbo-stratus and abolish the separate name, nimbus. (Recognizing alto-stratus as the real source of "nimbus" rain). Lenticular alto-cumulus is distinguished from turreted alto-cumulus because of their different indications as to stability of air masses. The use of these structural characteristics to identify the air mass formation constitutes <u>indirect aerology.</u> It is indispensable in present Norwegian methods of interpretation and analysis. It is also directly applicable to special forecasting problems of the Fleet. The European International Code provides code groups by which many of the above characteristics can be distinguished in reports. Lacking code provisions, the forecaster can in many cases deduce the actual observation from attending circumstances. For example, reports of nimbus or cumulo-nimbus with irregular but heavy amounts of rain usually show true shower clouds, not "nimbus"; a report of mist with other warm sector evidence usually means that the mist is drizzle.

14. With reference to isobars - the pressure field is drawn to interpret the observed facts. This is often significant in forecasting. The field, allowing for logical time changes, must fit the observed tendencies and barograph traces. The proof of the map lies in these traces. Later cases illustrate. With reference to fronts - they are drawn to simplify and explain the weather on the map. A front must be an effective discontinuity. A continuous change even though rapid is not called a front. For example, a large temperature difference between stations indicates a front only if it is due to a discontinuous change representing a boundary between different air masses. Complex situations with numerous fronts are regarded as occasional, not frequent occurrences.

15. A single weather map is used for all surface data. Reports are entered in pictorial symbols as far as possible. Position of entry is significant. Symbols and their arrangement are illustrated in the maps attached hereto. They are based on the International symbols. Auxiliary charts are used only for aerological data when too detailed for entry on the principal chart. Entry of clouds, pressure, tendencies, etc., all on the same chart is regarded by the Bergen school as necessary to rapid analysis of related elements. Topography, a major factor in all analyis and forecasting for mountainous and costal areas, is shown plainly on the map. Its basic importance is discussed with illustrations in later paragraphs.

16. AIR MASSES. The identification of air masses depends largely on indirect aerology. At present little use is made of specific humidity, potential and equivalent temperature and their related semi-conservative properties. No great emphasis is placed on formal classification of air masses. (Several classifications have been proposed in Europe and America). For convenience, names are given to commonly found air masses from certain sources. But their characteristics and limits are relative only. The basic distinction divides them into the two old classes - cold air masses (KM) and warm air masses (WM). The most used subdivisions are Artic Air (AL) and Polar Air (PL). Tropical Air (TL) and Equatorial Air (EL). Further subdivisions such as maritime polar air, or continental tropical air are used when necessary to emphasize a characteristic of importance in the current weather processes. In the order listed above (AL, PL, TL and EL), each air mass usually behaves as a warm mass to those listed in order before it, and as a cold mass to those listed after it. Arctic Air, always a KM, is rarely found in low latitudes. Equatorial Air, always a WM, is rarely found in high latitudes. The characteristics which are commonly used in air mass identification (Bergen school) are given in following paragraphs.

17. COLD AIR MASS. Low temperature, low humidity and high pressure as indications of a cold air mass carry less weight than formerly. A surface inversion may give low temperatures in a warm mass. Subsidence may heat portions of a cold air mass without destroying other cold mass characteristics. More weight is given to cloud and precipitation forms, visibility, wind and the periodical (mostly diurnal) changes in the weather elements. The clouds within the front portion of a cold mass, especially over oceans, are detached cumulus and the precipitation is in form of showers thereby indicating relatively steep lapse rate. A snow covered continent in winter may soon cause disappearance of these cold mass instability indications. The diurnal period

shown by cold mass clouds and showers is indicative. Over land, surface heating tends to give a maximum of cumulus clouds and showers in daytime (afternoon), but at night, surface radiation increases stability and reduces shower clouds to a minimum. Over sea, the diurnal period is reversed. There, cold mass clouds and showers show a maximum at night owing to slight steepening in lapse rate from the relatively greater cooling at the one or two kilometer level. Orographic influences have an important influence. On windward slopes the showers in a KM may merge and give the appearance of warm front rain. In such cases, if any report shows breaks in the cloud cover on windward slopes, it is an indication that the weather is of the cold mass shower type. On lee slopes, the foehn may completely dissolve the clouds and showers. Subsidence in the free air tends to dissolve clouds also.

18. Widespread fog is rare in a true cold mass. In a transitional cold mass, radiation fog may be reported locally in a morning observation over land, but this type can usually be distinguished from air mass fog which is indicative of warm air. Visibility is used to identify air masses through the following characteristics. The absolute transparency of the air is some indication. Arctic Air, since its humidity is low and it originates in a region free from dust, is very transparent. In Norway, visibilities in excess of a certain value are accepted as evidence of Arctic Air. To some extent also, certain other values of visibility distinguish Polar from Tropical Air. Over regions which are populous or flat, absolute transparency of the air is less useful because representative observations are difficult to obtain. Here diurnal changes are more indicative. For example, over land cold masses as well as warm masses often have a layer of ground haze several hundred feet deep in the early morning. But in the afternoon a cold mass shows improved visibility in the lower layers and decreased visibility in upper layers, while a warm mass shows little improvement in lower layers and relatively good visibility above unless it has the opalescence described later. These distinctions hold true for air masses over populous regions which have local sources of nucleii providing these sources are not too abundant and irregular. Reports from airplane observations or mountain stations are used to recognize the above diurnal changes.

19. Temperatures are used in special ways to identify cold masses. A small diurnal range when skies are clear indicates a deep cold mass. Several days sunshine are necessary to warm such a mass so that surface temperatures can rise decidedly. Cold masses, especially Arctic Air, show greater latitudinal temperature gradient than warm masses. Over oceans, an air temperature lower than water temperature is indicative of cold air mass.

A difference of 2 or 3 degrees F. is sufficient if the reports are representative of general temperatures of air and water. Over land, rapid absorption and radiation from the surface prevents use of this principle. For the same reason, a general temperature fall over land is used with caution for cold mass identification. In Norway, an Arctic Air mass is identified with certainty if temperatures and humidities fall below certain limiting values when winds are fresh or stronger. (Vapor pressure 0.2 mm. or less). The rule specifies that any mass with values below these limits can only be Arctic Air, but not necessarily all Arctic Air has values below the limits.

20. WARM AIR MASS. The cloud and precipitation forms which identify warm air masses are very low stratus, fog and drizzle i.e. "mist" - numerous small droplets falling slowly. These forms result from stability and high humidity in the lower layers of a warm mass. In the marine climate of northwestern Europe they are of frequent occurrence with warm masses. Similar relations probably apply to our North Pacific Coast. In a continental climate, warm mass drizzle occurs, but less frequently. Often the warm mass is clear except for the cumulus and cumulo-nimbus following intense insolation in lower latitudes. Fog and low stratus reports are not unmistakable evidence of a warm air mass. These cloud forms result also from expansional cooling as air approaches a deep cyclone center, and from conditions just preceding a warm front; orographical influences, etc. In general, advection fog forms in any warm moist current which is sufficiently cooled in the lower layers by passage over water. Several successive days of sea breeze may satisfy the requirements. Detailed discussion of fog processes as developed by the Norwegian School has been published (MWR supplement - H.C.W.). Observations have shown that there may be sufficient subsidence in a sea breeze to cause clearing of fog on the coast in daytime, a fact to be recalled in interpreting reports.

21. For Tropical Air, a distinctive feature in Northern Europe is the lowering of visibility due to opalescent turgidity (Bergeron). This is described because of its probable value for weather analysis and forecasting at sea. The opalescence referred to is not the bluish haze common over mountainous regions, and not the ground haze of surface inversions. It is a condition resulting from the very fine nucleii found in tropical air over Northern Europe. It extends to high altitudes in contrast to common surface haze and is so uniform that it is easily overlooked. On close observation it is noticeable as a slight whitening of the sky when cloudless. It is best recognized by land marks such as mountains distant 20 or 30 miles which are usually visible but which are made indistinct or wholly invisible by the opalescent

condition. Whether this is true and characteristic of all tropical air remains to be studied. While it is well known that transparency of warm air masses is normally less than that of cold air, it is obvious that reports of low visibility due principally to inversion haze, light fog, etc., cannot be used in above special sense to identify Tropical Air.

22. Over oceans, an air temperature higher than water temperature is indicative of warm air mass if the difference is relatively large. Over land, a large diurnal range on clear days is usually found in a warm mass. It is also characteristic that the north-south temperature gradient in Tropical Air is smaller and more uniform than in Polar Air. The air is stable. Isobars are therefore relatively straight and uniform and winds rather constant in direction and velocity. With Tropical, as with Arctic Air, certain limiting values may be used. Values of temperature may be determined for each season and region which mark the usual limits for air masses other than Tropical. When reports show temperatures exceeding these limits, they indicate Tropical Air. There are times also when observed temperatures in a Tropical Air mass with overcast sky are used as a conservative element by which to trace the mass from map to map. The characteristic is established for each case and is valid only for a day or two. Similar use of temperature, humidity, etc., for other air masses is in most cases less successful.

23. Aerological data are used to supplement the foregoing methods of determining air mass characteristics. Various functions of temperature, humidity and pressure are employed. Brief description of these is contained elsewhere in the report. In this respect the German methods as described in the notes for Templehof are further advanced because of the more numerous aerological stations in Europe.

24 to 30. Omitted.

31. <u>IDENTIFICATION OF FRONTS:</u> Changes in weather occur principally along fronts, the boundaries between air masses. The chief object of the analysis is location of the fronts and determination of their structure. For this purpose the examination of weather elements on the map differs somewhat from that used in air mass identification (paragraphs 16 to 23). The elements are rarely unanimous in their indications of fronts. Winds may point to one location, temperatures to another. Decision is made by "letting the elements vote", giving to each its appropriate relative weight. Since the relative weights vary with circumstances, no fixed rules are made. The <u>approximate</u> order of importance of various elements is given in the sequence used below. Here again selection of representative reports is paramount. Orographical and other influences, often overlooked, enter into interpretation of reports of wind, temperature, pressure, clouds and precipitation.

32. <u>WARM FRONTS:</u> In practice the sharpest front is usually studied first. Whether this is done before or after sketching the isobars depends upon the complexity of the map. In simple cases the fronts are sketched first and the isobars fitted to the fronts at once. In complex cases the pressure field is studied first by tentatively sketching the isobars and readjusting them to the fronts later. At the start the forecaster does not know whether the front he is examining is warm, cold or occluded. With all fronts, the <u>most important general principle</u> is that the front must show historical sequence. It must be a logical development from preceding maps. While this is an old principle, its importance is greatly increased in present methods. Only when evidence is very positive is a front placed where none could be expected from previous maps. Frontogenesis, a slow process, seldom occurs in the air masses remaining in view from map to map. It requires a particular wind field (a "neutral zone"). Almost invariably, apparent exceptions to this principle are traceable to faulty analysis. Frontolysis is also a slow process. Disappearance of a sharp front unless it has unquestionably passed beyond the map boundaries is viewed with suspicion. Usually it either lies hidden between reporting stations, or was fictitious on the preceding map. As expressed by Bergeron, historical sequence requires that every structure on the map "must be logical - Kinematically, dynamically and thermodynamically" for space relations and for time relations. Assumed structures which appear improbable are usually erroneous, not simply "unexplainable."

33. With this first requirement, historical sequence, satisfied, the next important evidence of a front is a system of clouds and precipitation. For warm front identification, the alto-stratus cloud system is typical. According to the Bergen school, a great expanse of unbroken upper cloud sheet (cirro-stratus and alto-stratus) is formed by slow "upglide" motion of a warm air mass over a slightly inclined surface, that is, a warm front surface (or some form of occluded warm front surface). Having discovered an alto-stratus system and its accompanying precipitation, the front is usually found near the "inner" edge of the rain and "nimbo-stratus." Upper fronts with no surface discontinuity are considered later. Inexact reports of warm sector drizzle sometimes hide location. An unmistakeable alto-stratus system even without rain indicates a front and altho weak at the time, it may be reinforced and is therefore important in analysis. The position of a masked front is sometimes found from cloud altitude (A&t) reports by applying the average slope of a warm front surface. (Distance from reporting station equals cloud height times cotangent of slope angle).

34. With marine climates and in high latitude, a true alto-stratus sheet usually gives a large overcast area, - an expanse of <u>unbroken</u> clouds. This feature is a deciding point in identification. It is of such importance (other reasons also) that the European cloud code distinguishes between ten tenths cloud amount and amounts of more than nine tenths but less than overcast. A report showing less than overcast is evidence against simple warm front structure. This distinction may be less significant for continental climates and in lower latitudes where the dense unbroken sheet of alto-stratus accompanying a warm front possibly is less extensive. The principle is important however. When considering cloud reports, it is necessary always to judge whether the observer has reported correctly or has confused alto-stratus, stratus, or strato-cumulus, etc. Such errors, discussed elsewhere, are frequent. In drawing the map an area overcast with alto-stratus is customarily shaded faintly with pencil to bring out its shape and orientations with reference to the front. Note that in analysis the alto-stratus sheet aids in identifying warm front structure, while in "prognosis" the warm front, now identified, is a basis for forecasting the kinds of clouds.

35. The condition of the sky over the region where the warm front approaches the earth's surface, (i.e., near the front itself) varies with humidity, temperatures of earth and air, etc. This variation obscures the front's position. The warm front cloud system often extends right to the front, the edge of the alto-stratus hidden by low stratus clouds and precipitation. These clouds may merge with a fog and drizzle system of the warm sector, or may be followed by a partly cloudy to clear warm sector. It is stated (Bergeron) that the alto stratus-pallionimbus clouds of a warm front system in high latitudes extend right to the front except when (1) an upper front precedes it, or (2) a broad but shallow layer of cool air exists ahead of the front, or (3) the warm mass is too stable to "upglide" (also low humidity). In such cases the clouds may cease a considerable distance ahead of the front. Individual cases are decided from study of alto-stratus system to drizzle, cumuliform clouds, or clear sky indicates termination of the warm front surface and in simple cases, proximity of the front.

36. The more or less continuous cloud observations by the forecaster locally as well as the observations reported from ships and stations are important in analysis. Here particularly the method applies to naval weather problems. If the clouds observed locally during the day do not fit the map analysis, the analysis is corrected. "The clouds are right; the analysis wrong". Verification or correction in this manner is an important factor in accuracy of forecasts. The subject frequently comes into discussion in Bergen forecast conferences. Ship observations of clouds carry weight because clouds are more representative at sea and the observer's vision usually covers a greater area. Such an observation, covering several thousand square miles at times, may give the first conclusive evidence of a frontal surface while the front is still far distant.

37. Some examples are cited to illustrate the numerous uses of cloud reports in the analysis. The presence of dense cirrus forms above an approaching alto-stratus area is favorable for early arrival or development of the alto-stratus rain. Lacking cirrus forms, rain usually does not occur (in high latitudes, at least). The dense cirrus sheet of a warm front gives approximately by its direction of movement and velocity the average direction of movement and speed of the warm front, this direction being about 45 degrees counterclockwise from the cirrus

direction. This applies to the denser cirrus, not the advance thin forms. (These direction relations differ from the old ideas of radiating cirrus). The boundary of the alto-stratus sheet roughly shows the orientation of the front. It usually parallels the front. A change in direction and a spreading of the cirrus and alto-stratus sheets are the first indication of wave formation on a quasi-stationary front. "Fallstreifen" not only indicate the development of rain conditions in an alto-stratus sheet but also by their curvature supplement pilot balloon soundings in showing the character of the frontal surface discontinuity. Strato-cumulus, the typical cloud formation just below an anticyclonic inversion layer (subsidence layer) may often be identified by means of its diurnal period and thereby air in identification of the atmospheric structure. If such clouds dissolve at night they are probably genuine strato-cumulus. If they show no diurnal period they are probably alto-cumulus belonging to a frontal surface, often incorrectly reported as strato-cumulus by the observer.

38. Next as an indication of warm front structure is the area of steady rain. For reasons given elsewhere, such rain is usually of alto-stratus origin; that is, the same atmospheric formation gives rise to alto-stratus clouds and steady rain. The relation between the edge of the rain area and the front and the variations therein are stated in paragraph 33. Orographical influences on pattern of rain area are also important and are discussed under examples. A ground slope of fifty feet per mile may greatly modify the rain pattern and therefore its relation to the front. In complex fronts and occlusions, the front may lie within the rain area, but in simple fronts it lies along the edge of the rain area. Front location is indicated also by changes in character, amount and rate of rainfall. The change from steady light rain to showers is analogous to change from alto-stratus to cumulus. Rain may reveal the transition when the cloud systems are hidden by low stratus. The evidence may be confused by occurrence of "moist labile" showers with the warm front, especially in lower latitudes, but in this case the pressure tendencies help the forecaster to distinguish such showers from those which mark a change in air mass aloft.

39. An abnormally broad precipitation area usually indicates the presence of more than one warm front surface. This frequently leads to discovery of a double front. There are relations between the area of snowfall, the air mass and the position of the front; also between the form of precipitation, whether sleet,

soft hail, snow, etc., and the front and air mass structure. Present knowledge of these relations is not sufficiently advanced to permit their immediate use. However, it is useful to recognize that a definite change in character of precipitation is due to a basic change in air characteristics of that locality and therefore usually a change in air mass. Often there are certain characteristics of individual fronts, such as pattern of rain area which aid in identifying that front from map to map. Excluding orographical effects, a line of heavier rainfall in a rain area shows the orientation of a front which may otherwise be hidden. The width, intensity and orientation of the rain area in a simple warm front is an indication of the strength and direction of the warm current aloft when pilot balloon reports are lacking. These characteristics are indirect evidence of convergence or divergence of the wind stream aloft, direction of movement of the system, etc. At sea, a warm front is usually followed by drizzle, the precipitation form typical of a warm sector. Over land, drizzle is less frequent but when observed it has usually the same significance as over sea. For reasons given elsewhere the front may pass through the drizzle area (<u>Note that reference is to true drizzle;not to light rain</u>).

40. Next in importance to clouds and rain as evidence of front structure, the barometric reports may be listed. Barometer tendencies and characteristics especially are significant elements. Any front passage is in general accompanied by a tendency toward pressure change in the direction of increasing pressure, that is by a less rapid fall, a change from falling to rising, or a more rapid rise. The amount and character of the change depends on individual structure, orientation and movement of the front. Studies of barograms with different combinations of structure, orientation, etc., reveal the relations which in reports of barometer characteristic, can be used to recognize a front. For a warm front the typical change is a decrease in the rate of fall of the barometer, or a change from falling to steady. Infrequently it is a change from falling to rising. Therefore, when the map shows an area with pressure characteristics of the form ⌊ or ∨ (falling then steady, or falling then rising) along a line where a front is suspected, the tendencies show the position of the front providing they are not too greatly influenced by diurnal range, etc. Similarly there is usually a front between two adjacent areas, one with barometers showing a well defined fall; the other a definite rise. Principle

fronts rarely pass directly through an important anallobar or a large high pressure center. In the rare cases when rapid pressure rise in higher layers produces a high or wedge with a front through it, the resulting divergence tends to make the front diffuse. Pressure tendencies are especially useful in tracing a front across mountainous country. Often when precipitation, wind and temperature are so modified by the mountains that they give no evidence, the pressure changes reveal the front's position. This states only that pressure change reports from mountain stations are often the best means for determining front movement, and not that the relation is always simple and direct. It is sometimes masked by diurnal changes, or by influence of the upper wave induced by mountain ranges. (See occlusions). These few examples serve to illustrate some of the numerous uses of pressure change reports.

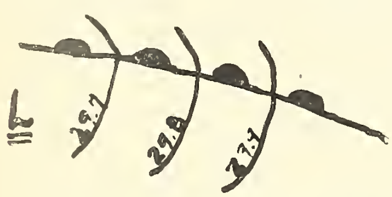
41. Closely related is the skilled use of the local barograph trace to recognize passage of fronts and fit them correctly to the analysis. Even for minor fronts, this practice is important in present methods. Examples given later are illustrative. The evidence is not always certain. Diurnal effects and large changes in the pressure fields of cyclones and anticyclones (rapid deepending or filling), etc., complicate the identification of frontal effects alone, but seldom obscure them completely.

42. In important cases the three hour isallobars are drawn to aid in locating a front. These are placed as dashed lines on the weather map, not on a separate auxilliary chart. The purpose is to bring out their relations to other elements. Since usually a front is preceded by a katallobar and followed by an anallobar these may reveal its position when cloud, rain, etc., indications are complex. These details are not so plainly shown in the larger period pressure change maps (6, - 12 or 24 hour), which therefore are seldom drawn. When drawn, the 12 or 24 hour isallobars are used to obtain further evidence of movement of centers. Katallobars concentric with cyclone centers are of course typical of occlusions. In advanced "stages" several weak occluded fronts may be present in an occluded cyclone with the usual allobaric relations hidden by the general katallobar. Later examples illustrate probable errors in isallobars when reports are sparse. Comparison with preceding pressure reports (6 or 12 hours before) and weighing of the possible interpretations usually yields a correct conclusion as to structure. In using pressure tendency reports from ships, a correction must be made for the ship's movement. A ship moving at right angles to the isobars at 15 knots may have an apparent tendency which hides the real tendency at a stationary point. The correction is obtained by applying the ship's course and average speed.

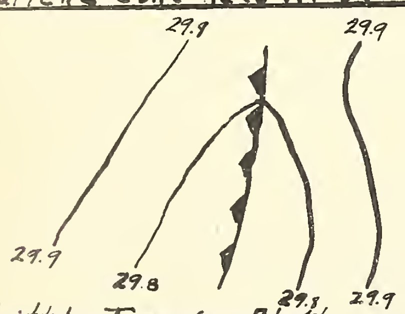
43. Front position is shown also by shape of pressure field. A front is defined as a boundary between air masses, a wind discontinuity. It is often too weak to be discovered in surface wind reports, especially over land. The accompanying pressure discontinuity also may be hidden, but pressure reports are more likely to be representative than wind reports, and usually the discontinuity can be seen in accurately interpolated isobars. Often it is revealed only by intermediate isobars to five hundredths of an inch or less. It is evident that any change in direction of isobars associated with a front is toward the lower pressure side. Such isobars are always concave toward lower pressure. Cf. "Wind always veers with passage of surface front - a line of converging winds". A front is sometimes shown by differences in the pressure gradients in two adjacent areas. This is equivalent to stating that the two air masses on opposite sides of the front have different wind veloc-

ities. This may be entirely missed in the surface wind reports and yet show clearly in the pressure field. The isobars if correctly oriented and spaced, reveal this fact. (See references ________ Geoph. Memoir #50 1930 Bjerknes). At sea, where wind reports are more representative, the correct orientation of isobars with reference to wind and barometer is especially important in locating a front. Even though ship reports are sparse, the isobars accurately drawn from two ships not in the same air mass place the front at their intersections. In drawing isobars, the pressure tendency reports serve as intermediate observations to aid in correct interpolation and spacing. The isobars are drawn so as to produce the reported tendencies.

44. The Bergen school makes much use of the probable relations between surface isobars and winds at moderate altitudes to estimate upper winds when pilot balloon reports are lacking. Three examples illustrate. When reports show conclusively that crowded isobars (steep gradient) extend across high mountain ranges with little interference the forecaster knows that he has a very deep wind current to consider. (See U.S. Map Jan. 20, 1931). Warm mass isobars meeting a front at approximately right angles indicate that the warm current continues aloft far beyond the front. Isobars paralleling or meeting a front at small angles show little transfer of air aloft across the front. (Examples at the left.) The principle is applied also to drawn isobars correctly from known wind fields.



Current Continues Aloft



Little Transfer Aloft

F.A.

45. The relation of front movement to pressure gradient is illustrated later. (Examples). Gradient shows not only the movement of the front, but also the character, whether warm or cold, providing the air masses have been identified. The Bergen school emphasizes that a surface front usually moves consistently with reference to the pressure field. Distance and direction are estimated from corresponding gradient in the cold mass, using component normal to the front. This is a rough working rule. Sources of inaccuracy are the occasional large differences in pressure fields between the lower and the intermediate layers, and marked subsidence or "upglide" motion along the front. But the rule holds true in most cases. As a quick means for getting the component, a celluloid scale is used in Oslo. It is based on latitude and distance between straight isobars as arguments. Study of

average gradient since the preceding map often shows location of a front otherwise lost. This is one of the basic and most useful of present frontal principles.

46. Since wind and pressure fields are closely related, their frontal indications are similar. As result of surface influences, wind reports are usually less representative than pressure reports. They therefore require careful interpretation. It is well known that shifts in wind direction and changes in wind velocity often accompany fronts. But sometimes a front is erroneously drawn along an apparent wind shift on the map which actually is a slow veering. In code reports to eight points, such an error is easily made. For example, if there is a steep gradient on the eastern side of a low a group of stations may have SE winds; another group, just south of the first, have SExS winds; a third group just south of the second, have SSE, a fourth SxE and so on, in a homogeneous air mass. But in the coded reports to eight directions, the more easterly and northerly groups report southeast and the southerly groups report south. The line between those reporting southeast and those reporting south may be mistaken for a front. Interpretation as a warm front would apparently have support in the higher temperatures reported by the more southerly stations. Actually the temperature difference may be due only to the usual north-south temperature gradient. Confusion is increased by the fact that the temperature differences accompanying a true front are often smaller than those resulting only from the "latitudinal" differences within the same air mass. The distinction (front change relatively discontinuous; latitudinal change relatively continuous) may not be apparent on the map. The best precaution against such error is to make the analysis satisfy historical sequence as regards previous position, pressure gradient, etc. The limit of a warm air mass and therefore the front often appears as the boundary of a wind current of uniform velocity and direction, a characteristic of stable tropical air masses.

47. Among the relations between wind field and movement of front (or cyclone center) may be mentioned that most cases of retrograde movement occur either when there is an active (often reinforced) warm sector opening eastward, or when an occluded cyclone is surrounding by a wide spread easterly wind stream. A warm front in which the isobars on the cold side are almost parallel to the front and closely packed remained practically stationary perhaps for several days as when the front is a principal front (Arctic Front) and the cold east wind blows with considerable force, obviously fitting with the crowded east-west isobars. The warm sector air in such case ascends the frontal surface without advancing the front on the ground. See U.S. maps June 18-21, 1930.

48. Basic changes in the use of surface temperature reports have been made by the Bergen school. Originally, temperature was regarded as one of the principal elements by which to identify fronts. This view led to fundamental errors in weather map analysis. Surface temperatures are now regarded as among the least reliable of frontal characteristics. Applicable principally to surface temperatures, this sometimes is true of temperatures aloft also. The reasons are evident, surface temperature variations in the same air mass result from local features such as differences in altitude, radiation, snow cover, etc. These variations are often much greater than the representative differences on opposite sides of a front. Uneven subsidence in an air mass produces temperature differences not representative of the mass as a whole. The diurnal range introduces uncertainies. Consequently, temperature reports are now used as confirmatory evidence, not primary evidence of front. If the position of a front is known approximately, study of the temperatures may show its position definitely. For this purpose, time changes in temperature if available in the reports, as well as space changes are useful. Reports of extreme temperature (max or min) can be used to estimate time changes.

49. In general for warm fronts, the "ground" front is drawn at the end of the associated temperature rise. However, with a rapid moving front which has left a shallow but broad layer of cold air no longer effective as a frontal surface, it may be necessary to show the surface front near the beginning of the associated temperature rise. Other circumstances determine. If temperatures aloft are reported it is usually, not always, possible to recognize whether or not a temperature change has occurred thru an altitude range sufficient to mark it as a true discontinuity. The distribution and indications of temperature along a simple warm front (Bjerknes and Solberg "classical" type) are well known and need no discussion. Examples given later illustrate how surface temperature differences may be misleading.

50. The above objections do not prevent use of temperature reports when circumstances show that the discontinuity is unmistakeable evidence of a front. The study of numerous cases for Western Europe has enabled meteorologists there to find characteristics useful in identifying fronts, but the characteristics do not necessarily apply to other continents. Similar studies will have to be made for other climatic regions. Temperature observations are given relatively greater weight in front identification in mountainous regions. Here they often stand close to pressure tendency in importance because they are large local modifications of clouds, absolute pressure, etc. The use of temperature change (24 hour) is often conclusive evidence, especially if allowance can be made for differences in cloud cover

during the preceding periods. Valley temperatures are likely to be more representative in afternoon than at night. Summit stations are usually representative when winds are force four or greater.

51. Humidity reports, like temperature, are relatively unreliable for front identification. Their use in Norway is not standardized. For current analysis where speed is essential, humidity is usually expressed as dewpoint. Its use rarely extends beyond the simple principle that an increase in dewpoint representative of an actual air mass change typifies a change to Tropical Air, while a marked and representative decrease indicates a change to Polar (or Arctic) Air. Although not among the most important elements in analysis, humidity (dewpoint) not infrequently carries the "deciding vote".

52. COLD FRONT. The principles used in finding positions of cold fronts, stated briefly below, are given in an order similar to that for warm fronts, the most important criteria first. Here again, circumstances alter relative importance.

53. Cold fronts are given the test of historical sequence in the same manner as warm fronts. This principle can scarcely be over emphasized as a primary rule in Bergen procedure.

54. Characteristic clouds resulting from the instability of cold fronts are indicative of the position of such front. The usual forms are cumulus (towering) and cumulo-nimbus occurring with or just behind a cold front. To these may be added special forms of alto-cumulus, for example, A Cu castellatus and cirrus which sometimes are reported ahead of a cold front. Although code reports do not distinguish between all of these forms, it is often possible to recognize them with reasonable certainty in the associated reports. The presence of these upper cloud forms sometimes complicates analysis of the cold front. A narrow zone of cumulus or cumulo-nimbus clouds followed by clearing often shows the position of a weak cold front which is not easily found in other elements. Some cold fronts are followed by a zone of subsidence sufficient to dissolve the shower clouds and leave a wide band of clear sky between the frontal clouds and the instability showers of the cold air mass. With reference to cloud amount, the boundary between an overcast area and a partly cloudy to clear area may mark the front between a warm air mass with stratus clouds and a cold air mass with cumuliform clouds (marine climate); or the boundary between a clear area and a partly cloudy zone may mark the front between a clear warm sector (continental) and the advancing cold mass. Except for the narrow strip along the front where shower clouds often merge and cover the sky, a cold front is typified by detached clouds in contrast to the overcast sky of a warm front surface. While cold front cloud types are not as frequently confused by observers as are warm front types (e.g. confusion of stratus, strato-cumulus with alto-stratus), the reports are not without observational errors. A considerable technique has grown up in interpretation of clouds as indicative of front structure. Some of this is given in the illustrations.

55. Subsidence in an advancing cold mass, evidenced by upper air data, pressure field, etc., plays an important part in interpretation of cold front clouds. Subsidence immediately behind the front gives rapid clearing, often followed in a few hours by a low strato-cumulus system in zones where the subsidence surface has formed a "lid" over surface convectional clouds. Obviously temperature gradient and humidity in the lower layers must be favorable for such clouds to form, features which are studied in the history of the air masses concerned. Other effects of subsidence will be found.

56. Precipitation is an important element for cold front identification. Shower precipitation (relatively heavy and brief) is typical of cold fronts in contrast to the light, steady and prolonged rain of simple warm fronts. Reports of character of precipitation give direct evidence, and reports of amount and duration, indirect evidence as to whether precipitation is of cold front origin. Frequently a cold front is plainly shown on the map by the edge of advancing precipitation, either active or past. It is useful to extrapolate from the hours of occurrence of cold front thunderstorms to fix the position of a front between stations. Isochromes of time of occurrence of precipitation aid in finding the front. Prefrontal precipitation may give confusing indications. (See later paragraph). When front structure is such as to give a certain zone of prefrontal rain, the characteristic tends to persist and is useful to fix the position of the front on the succeeding map. It is not common for a front structure to change so quickly as to show opposite characteristics on two consecutive maps. This principle is used much to identify occluded fronts.

57. Other characteristics in the precipitation and cloud forms aid in recognizing showery conditions and indirectly point to cold front type, for example size of rain drops. Such things are indicative only, not positive identification marks. Taken together they are often conclusive in identifying front structure, especially when the front passes the forecasters station.

58. Prefrontal rain may be incorrectly explained as due to overrunning far in advance of the cold front. In general, such explanation is justified only when supported by upper wind observations, pressure field, etc. Recent research has indicated that the cause of most prefrontal thunderstorms lies in the upper wave formation described recently by Bjerknes. (See paragraphs on occlusions and list of references).

59. The instability showers which occur in a maritime polar air mass are usually scattered and without systematic arrangement. There are many cases, however, when showers at first sight taken as accidental, can be logically related to an old occluded front. This gives

a basis for forecasting these showers more accurately. The Bergen school is reluctant to class showers as accidental and does so only when certain that they have no logical relation to a front. When air mass instability is favorable for scattered showers they naturally form first along an old front where conditions are still more favorable.

60. Distinction must be made in the analysis between true cold front showers and the showers resulting from radiation at night from the upper surface of stratus systems. Character of air mass, cloud forms and lightness of precipitation usually enable the forecaster to recognize such cases.

61. Pressure tendencies, isallobars, pressure field and gradient aid in recognizing and locating cold fronts as they do warm fronts. Characteristics (pressure) given under warm fronts could be repeated here. The typical barometer tendency is change from steady or falling to rising rapidly. Individual cases vary from strong fronts with greatly increased rise to weak fronts with only a temporarily decreased fall, the variations due largely to differences in intensity of front, and orientation of pressure field around it. Isallobaric indications of cold fronts are often well defined. As with warm fronts, a cold front movement is estimated from gradient normal to the front in the cold mass, an old principle often insufficiently utilized. As with all fronts, pressure field and front are fitted together. Neither is arbitrarily fixed and the other drawn to it. The front and the pressure "Vee", great or small, are drawn to explain the observation.

62. Because the advancing cold air mass is usually unstable, surface wind reports are more representative behind the cold front than elsewhere. Not overlooking the limitations mentioned under paragraphs 46, 63 etc., the front is not infrequently found by the change in wind direction and wind velocity in a zone where historical sequence, etc. leads one to expect it. The occurrence of wind increase with passage of a cold front is useful evidence when observed. However, counter clock wise movement of the front with respect to the low center brings it eventually into a pressure field where the wind shift is slight and the subsequent change to northwest in the form of a very gradual veering behind the front. This feature is most frequently found in occlusions. It follows therefore that wind reports as ordinarily given on the weather map are used to fix a front only if other important elements confirm the position, or at least are not contradictory.

63. For cold fronts as for warm fronts, surface temperature is uncertain evidence of front position. Subsidence in the spreading cold mass modifies its temperature and masks the original

temperature discontinuity. This effect together with the wind effect just referred to (preceding paragraph), gives the front an apparent position to windward of its true position. See examples. The practice of placing a front solely on temperature contrast leads to error especially in a fresh Polar or Arctic air mass because here the "continuous" horizontal temperature gradient is greatest and therefore, most misleading. In such an air mass, the temperature contrast between adjacent stations is often greater than when there is a true cold front. According to Bergen school, it is a common error to draw secondary cold fronts based on such temperature contrasts when they are not effective discontinuities but only rapid, continuous changes. The evidence lies in the accompanying barograph and thermograph traces, and in the failure of the supposed fronts to meet the requirement of historical sequence, not withstanding the foregoing, there are many cases in which a cold front has the simple type of temperature discontinuity which is useful in placing the front. Such cases recognized in the accompanying elements of cloudiness, diurnal ranges, etc., and the front is correctly located when drawn at the beginning of the temperature fall associated with it. (A rule opposite to that for warm front).

64. Humidity (dewpoint) reports in the rear of cold fronts are more representative than in vicinity of warm fronts and are therefore more useful for cold front identification. They are most useful when the cold front is dry and the wind strong. Some use has been made of specific humidities, lapse rates, and other functions of temperature and humidity. These elements, for reasons mentioned elsewhere have not been reduced to regular use in analysis.

65. and 66. Omitted.

67. OCCLUDED FRONTS: UPPER FRONTS: UPPER WAVES. European analysis have shown that most storms occlude quickly. The majority of fronts therefore are in form of occlusions, or upper fronts, a still further advanced stage. At the instant of occlusion the warm and cold fronts coincide along a line at the earth's surface (approx.). If the telescoping movement continues, one of the fronts, usually that bounding the warmer of the two cold masses, is forced aloft. This front subsequently exists only aloft unless regenerated as discussed later. Its position is shown on the map by a dashed line along its projection on the earth's surface, - dashed to distinguish it from a surface front. The two fronts (surface occlusion and upper front) may continue to move farther apart in this reversed position and both remain significant. Usually the upper front becomes the

more important as regards precipitation. Examples are shown elsewhere. Since occluded and upper fronts result from a combination of warm and cold fronts, they show a great variety of characteristics, in fact any combination of warm and cold front characteristics. Because of their complexity, methods of identification are less certain than for simple warm or cold fronts. The characteristics most useful in identification are given briefly below. Others are illustrated in the examples. Certain features of the subject have been discussed in more detail by Bergeron and by Refsdal (references---- and _________).

68. The first principle, historical sequence, has great importance in examination of occluded fronts because of wide variation in occlusion characteristics. Current observations alone are rarely conclusive in identifying an occlusion. Its position and structure on the present map must represent a development consistent with the observed facts of pressure, wind, clouds, etc., as given by previous maps and intervening observations. This test is applied without difficulty when the suppose occlusion is a surface front. Its application to upper fronts is more difficult because of lack of definite data as to pressure fields etc., at the higher levels which are related to upper front behavior. Upper fronts are nevertheless made to satisfy the requirement as far as possible with data available, a practice which often corrects an erroneous analysis.

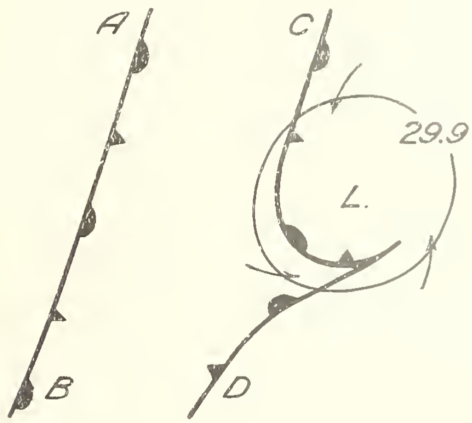
69. Clouds and precipitation are often good evidence of occluded front position. In simple types an alto-stratus system resembling that of a warm front is found ahead of the occlusion, and a cumulonimbus system more or less obscured by persistence of the altostratus and pallionimbus sheets follows immediately behind the occlusion. The two systems obviously overlap in most cases. Since the resulting cloud combinations are complex and difficult to identify, a better index of the front's position is often found in the character of the precipitation. Change from steady rain (alto-stratus type) to showers (instability type) usually marks the front. There is a possibility of confusion when showers result from moist labile instability as mentioned elsewhere. A very useful characteristic is the persistence of the rain pattern associated with a given occlusion. In most cases in which the rain area has the same definite pattern on successive maps, the occluded front occupies the same position relative to it during the entire period. Similar characteristics are shown by upper fronts. Evidence of an upper front is usually found in a rain area with a regular boundary which lies some distance from an occlusion with a rainless zone between and with the rain boundary accompanied by barometer tendencies typical of front passages. The distance between the boundary and the surface front (occlusion) shows a progressive increase from map to map. See illustrations.

70. Since the "upglide" movement of an occluded front surface is often weak, the alto-stratus system shows many variations. Alto-cumulus types are frequent, also irregular alto-stratus which are easily mistaken for strato-cumulus by observers, the height of the clouds being greatly underestimated. In such cases the forms can sometimes be distinguished by noting the presence of small fragments of high fracto-stratus or fracto-cumulus formed as result of "fallstreifen". The height of these frato forms as well as their origin demonstrates that the clouds above (usually overcast sky) are alto-stratus, not strato-cumulus. The Bergen school regards cirro-cumulus as generally the same in form and origin as alto-cumulus, only smaller and higher, and in analysis makes little distinction between them.

71. Pressure and wind are used in recognizing occluded fronts much the same as in warm and cold fronts. A distinctive feature is that the pressure field around an occlusion is likely to show a sharp Vee. This follows from the process of "squeezing out" the warm sector isobars and bringing together the two barometric systems of the opposing cold masses with their greater isobaric curvature. The Vee field around a loop occlusion results in a crowding of the isobars where the Vee terminates in the general pressure fields and gives increased winds (gales) often found at the tip of the loop occlusion. This feature sometimes aids in front identification. (Loop occlusions are shown in examples later). In agreement with the pressure field, the winds usually show convergence along an occlusion, and for reasons referred to above the change in wind direction with a recently occluded front is relatively great. In old occlusions the shift becomes very weak or is lost. It is typical for a loop occlusion to show a wind shift of 45 to 90 degrees. Its approach causes an "unexpected" backing of the winds some distance in the rear of the original occlusion. This feature serves to identify a loop occlusion on the map. Upper fronts also may show a wind convergence but it is usually slight or entirely hidden unless wind reports are available to thirty two points.

72. It follows from the foregoing that barometric tendencies also show the "effects" of occlusions and upper fronts. The tendency reports are among the most important evidence of occlusions, especially when they occur as double fronts, more or less masked by wide rain areas and strong winds. These tendency indications are similar to those for warm and cold fronts, and are therefore not repeated here. Even weak occlusions show some effect on the microbarograph. When a line of pressure tendency reports confirm one or two other indications of the location of an occluded front, the evidence may usually be taken as conclusive.

73. It occasionally happens that the general pressure field is favorable for an occlusion to approach a small cyclone. The occlusion clearly cannot enter the cyclone center as a straight line unchanged by the cyclonic circulation. This fact is sometimes important in the forecast. The occlusion is modified as indicated in the diagram, the line A-B representing a position during its approach, and C-D, a later position. In the rear portion of the cyclone the occlusion would become attenuated; in the front portion it might be sharpened. This situation is limited mostly to weak occlusions and weak cyclones although sometimes a large cyclone brings in outside occlusions in a similar manner. In no case does an outside surface front move with freedom into or out of a low center as a straight line. Usually when there seems to be evidence of such behavior, it is due to an upper front.



74. Temperature and humidity reports may cause an occluded front to be mistaken for a warm or cold front unless other evidence is given proper weight. The practice with reference to temperature and humidity as related to occlusions and upper fronts is implied in the paragraphs on warm and cold fronts.

75. UPPER WAVES. Certain features in the behavior of fronts and accompanying weather indicate the influence of an upper wave formation in the substratosphere. The indications have been substantiated by detailed studies of upper air conditions in connection with fronts. The formation and its substantiating evidence are too long for inclusion here. It will subsequently appear in published form. (J. Bjerknes paper to Brit. A. A. S.). Essentially, the theory is based on the principles demonstrated by Eckman expressing the effect of a bottom barrier on the flow on an overlying ocean current. An analogy exists in the flow of upper air currents over the "barrier" of a cold air mass. The result is a deflection of the upper currents in a manner to cause a wave-like deformation of the tropopause. This in turn, due to the relatively large slope of the tropopause in middle latitudes, results in importation of potentially colder air aloft, increases the lapse rate and produces instability progressively from aloft downward. The place most favorable for the latter effect is above the cold front surface, that is in a section where the upper air current is permitted to increase its depth. The process

explains some forms of prefrontal rain. It explains the turreted alto-cumulus and thunderstorms which precede some cold fronts. Once started, such a wave deformation may travel ahead of the barrier where it originated. It may continue for some distance after its associated front has stopped, and it if overtakes an old front, it may reinforce that front. See example, U.S.S. Los Angeles, June 26, 1930 map. After occlusion, deflection of the currents aloft would tend to occur farther to the rear, a fact which agrees with observed results. (Lagging of shower area, Etc). The wave phenomenon probably takes on complex forms in cases of loop occlusions and is perhaps the cause of the erratic behavior sometimes observed in upper fronts and associated thunderstorms, etc.

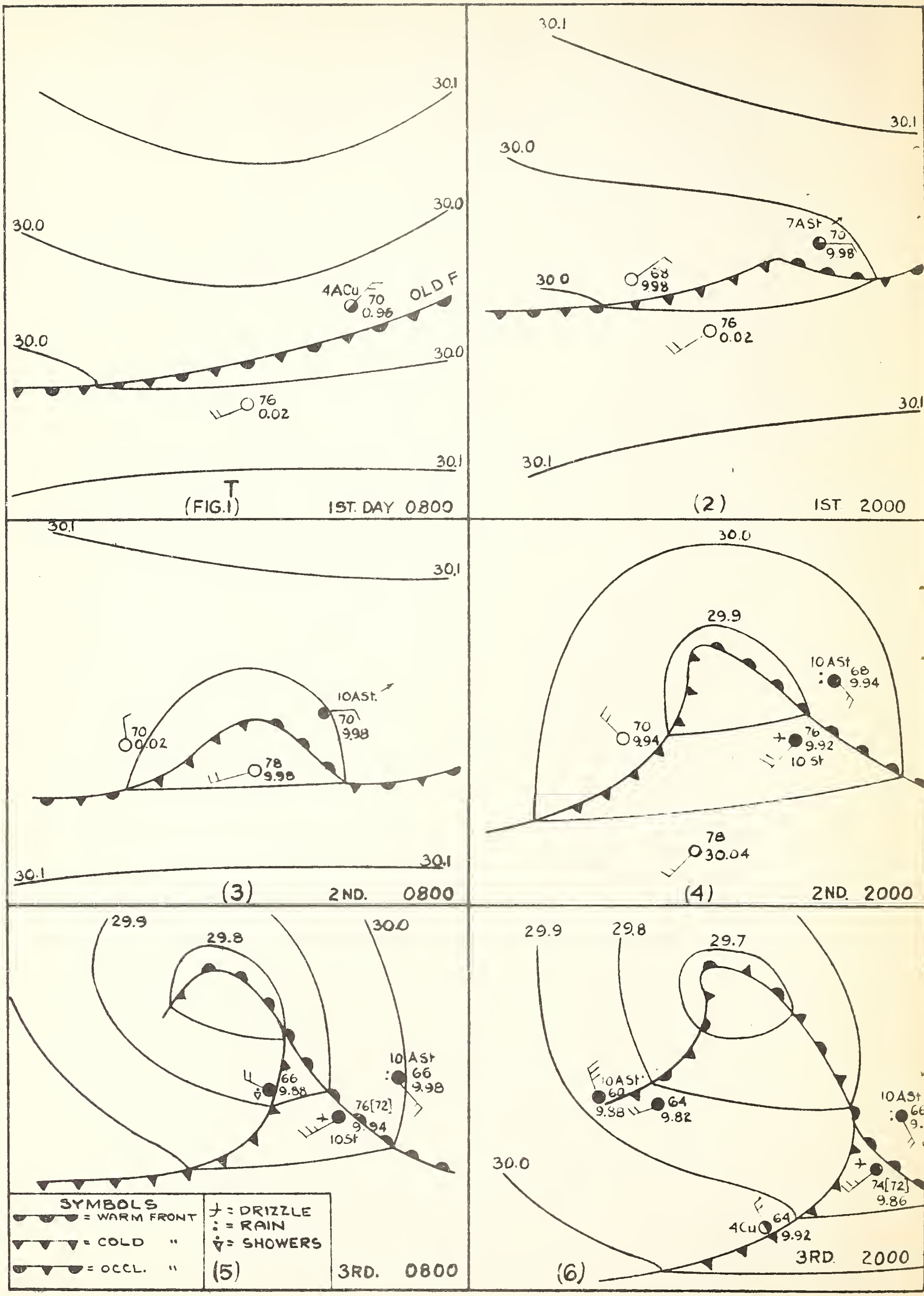
76. It is to be noted that a pressure trough aloft whether due to an upper front or to a wave phenomenon may impress its field upon the surface isobars and thus set up a wind contrast in the lower layers. If the field is approximately stationary the lower winds gradually build up a true discontinuity which becomes an active surface front.

77. A mountain range may also constitute the barrier which produces the upper wave referred to above. The wave so started may reinforce an old front lying to leeward, or hasten frontogenesis in a foehn low. It is a factor to be taken into account in forecasting for regions to leeward of mountains when upper winds are favorable for its development and especially when an old front lies over the region. Further studies are being made of upper wave formation and the apparently related phenomenon (wave crest) which causes abnormally large movement of an anticyclone in cases when movement cannot be ascribed solely to translation of air mass.

78. FORECASTING. The principles used in the analysis ("opignosis") are used again by the forecaster to project the pressure and wind fields, the fronts and accompanying weather for periods of 6,12,24 or 36 hours into the future and thus prepare the "prognosis". Analysis and forecast excluding time given to forecasters conference require sixty to ninety minutes providing the preceding map has been correctly analyzed. Obviously not all of the detailed tests outlined in the foregoing paragraphs can be applied to every station. This is not necessary. Careful interpretation of a few representative stations followed by examination of reports along the probable positions of fronts is usually sifficient. The procedure can in practice be fitted to ordinary forecast routine with less than thirty minutes increase in the time usually required for forecast, a small increase compared with the results. Forecasts by the Bergen school are detailed and, considering the geographical location, remarkably accurate. The forecast verification system, resembling in strictness and detail that used for form N.Aer. 447 (USN) sets a high standard. The forecaster usually does not accept a technical verification if in a practical sense the forecast was not satisfactory.

79. An important part of the forecast procedure is the daily conference of the forecasting staff held just after completion of the morning map and before the forecast is completed. The conference, notwithstanding a few disadvantages, is regarded as indispensible. With a logical method of analysis and forecasting there is good basis for discussion. The conference helps in discovering inconsistencies in analysis and aids in shaping the analysis to fit all weather conditions observed locally. During conference, the probable vertical structure is visualized by use of indirect aerology to supplement available upper air observations. The probable displacement of the "axis" of a cyclone or anticyclone with altitude as indicated by upper winds and cloud movements ("warm air lies to the left") is frequently discussed in relation to future development of the pressure field. A comparison of such structure with the mean positions of fronts and mean (climatological) structure as shown by averages of pressure and temperature aloft (CfC Shaw Manual II) is used to estimate cause and behavior in individual cases. The mean upper air charts also are used to study regions climatically favorable for frontogenesis or frontolysis. A "climatic neutral point is closely examined for new formations. For example the general area of Mexico and the west Gulf. In summer, the front between the trade winds and the equatorial air off West Africa may be a region of cyclogenesis. The seasonal differences in temperatures of general air masses are of course studied. The Azores Area of tropical air, for example, acts as true tropical air in winter, but often as polar air in summer. There are zones where a stable air mass serves as a front barrier, e.g. the Arctic frontal zone, or the Atlantic tropical High ("Bermuda High"). Such a zone may be identified by the pressure and wind fields but sometimes only by the evidence of its effect on fronts in the past. These subjects are of special interest for their bearing on forecasts of longer range. There are periods for instance when a tropical air mass becomes well established over an area. It is usually stable and inactive. Its generally fair weather continues until there is evidence of a strong polar outbreak moving southward to displace it. This principle has been used in southeastern United States as well as in Europe. Certain studies are being made in Europe to further develope the system of longer range forecasts based on these principles. The possibilities look promising although not certain. Their value for naval purposes is evident.

80. to 100 incl. - Omitted.



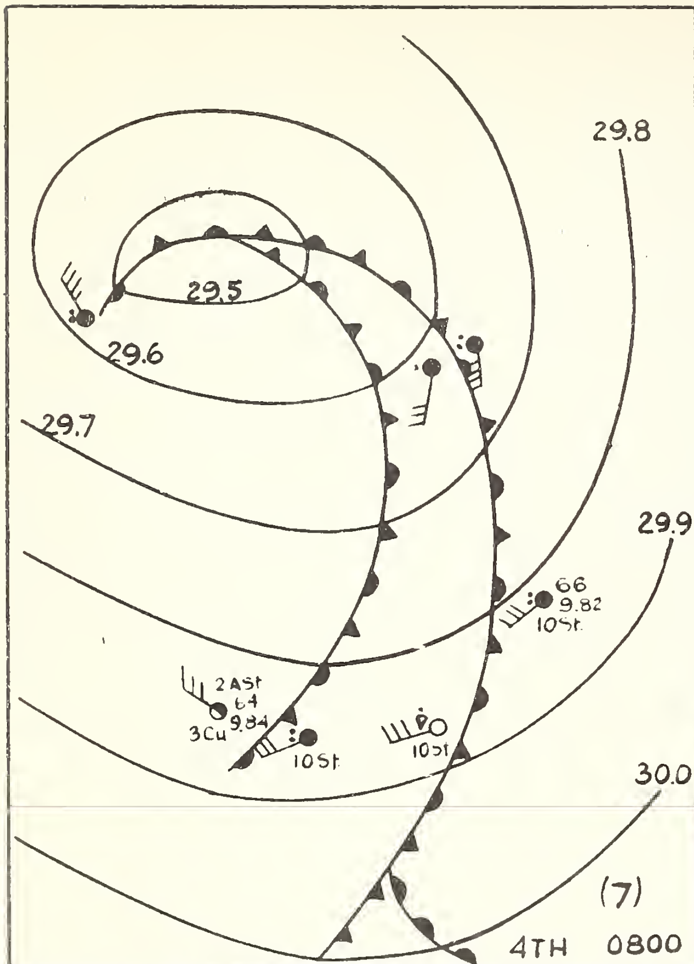
TYPICAL STAGES AND REPRESENTATIVE REPORTS IN A MOVING CYCLONE OVER THE OCEAN

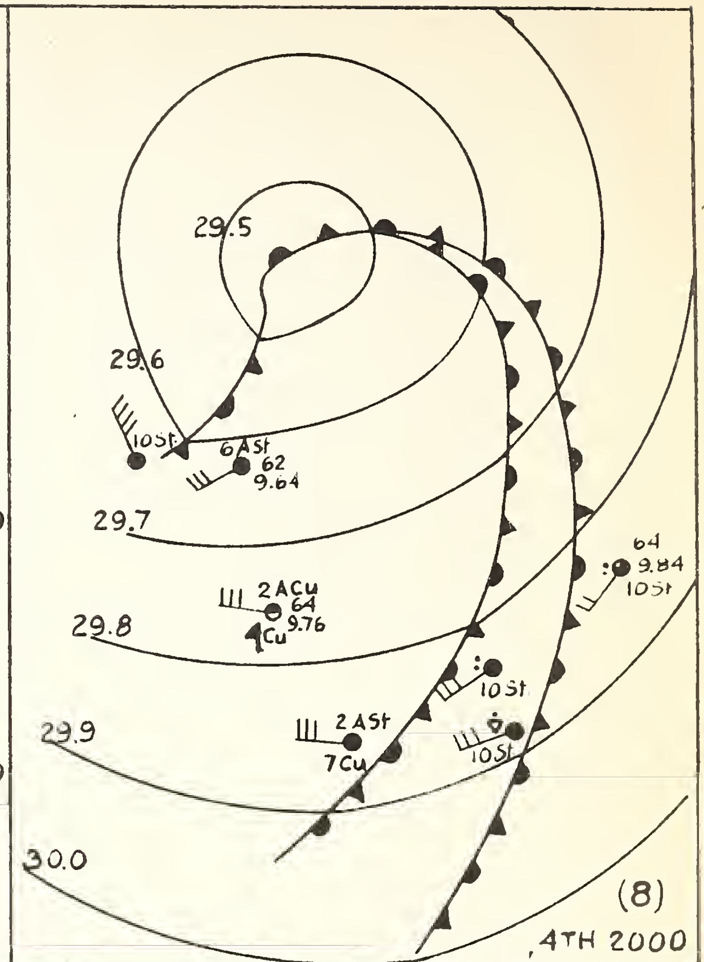
101. The diagrams which follow are to show the development of certain front formations and to illustrate the present methods of the Bergen school. That present methods differ in important respects from methods in use elsewhere and that they lead to more satisfaction in frontal analysis is quickly seen by comparison of the maps and analysis from different institutes.

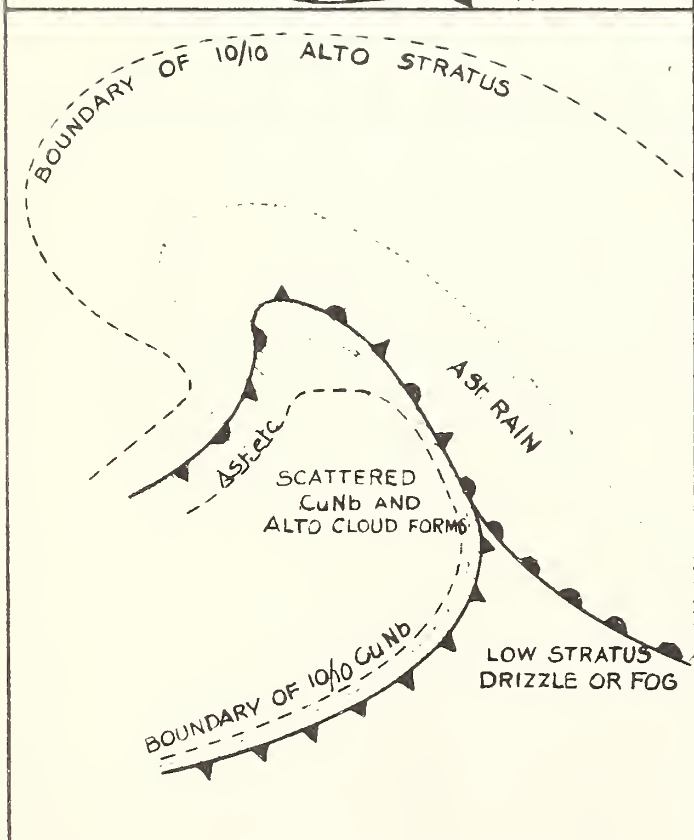
102. The Bergen view point in analysis holds that the map must picture the frontal structure, the wind and pressure fields, etc., in their true and logical forms. Isobars must be more than contour lines thru given reports of pressure. The forecaster must interpret the always inadequate data so that the isobars and fronts explain the casual relations among the weather elements to the best of his judgment. Data are "always inadequate" because of the inaccuracies in observations and reports, the limitations imposed by synoptic codes and the sparseness of observing stations. In illustration of the viewpoint, the forecaster knows that barometer readings are reported only to nearest even hundredths of an inch (U.S.). When several adjacent stations report 30.00, he knows that the actual readings may very from this by plus or minus .009 inch, possible total variation of .018. He must judge from accompanying conditions whether the thirty inch isobar "fits" the analysis if drawn thru these stations, and if not, he presents a more accurate picture of the conditions if he draws the isobar in accordance with the probable structure, passing <u>by</u> (not <u>thru</u>) any or all of the stations reporting 30.00, providing the distance of the isobar from any station so reporting does not exceed the limits, plus or minus .009. This illustrates the principles which are applied also to clouds, active rain and other elements in arriving at a logical explanation of the weather.

103. Formations which are structurally impossible are eliminated. Such formations, overlooked by some institutes, may have led to incorrect forecasts, especially for detailed forecasts. For example, a sharp acute angle in crowded anticyclonic isobars (i.e. vertex of angle away from "high"), or rounded isobars thru a sharp front, or a simple loop occlusion bent clockwise to a position close to the "parent" warm front are structurally illogical. The emphasis placed by the Bergen school on correction of such errors is not academic only. If the analysis is to serve as the basis for a detailed forecast, it "must be dynamically and kinematically logical".

104. Conditions which may lead to the formations shown in subsequent illustrations are pictured simply in figures 1 to 10, diagrams of a wave disturbance which develops into an ideal cyclone. Isobars and weather reports typify the pressure fields and weather distributions often observed during development of such a cyclone over the ocean. The loop occlusion (Bjerknes "bent back occlusion") beginning with figure 5 was not recognized in the original

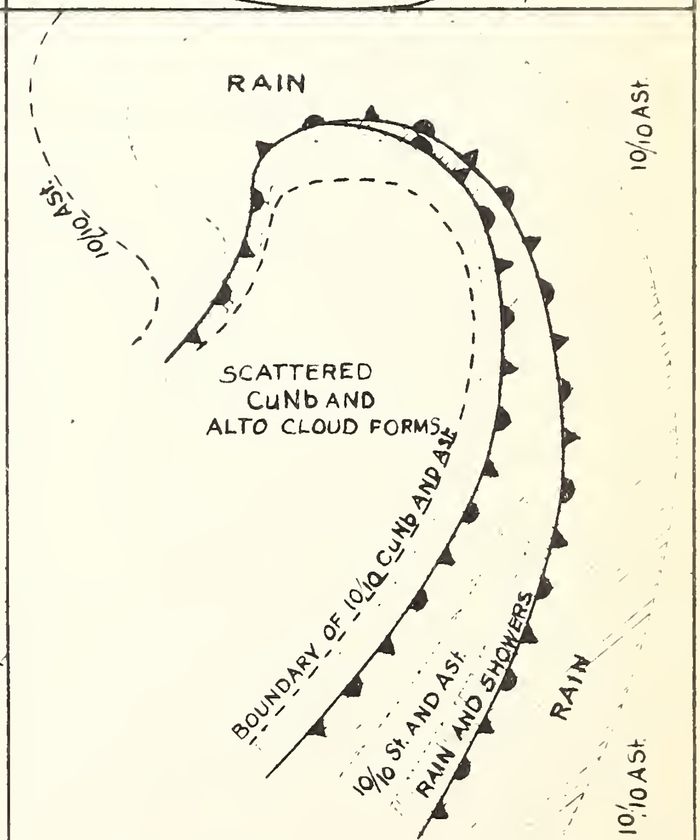






CLOUDS AND PRECIPITATION FOR (FIG.6)

(9)



CLOUDS AND PRECIPITATION FOR (FIG.8)

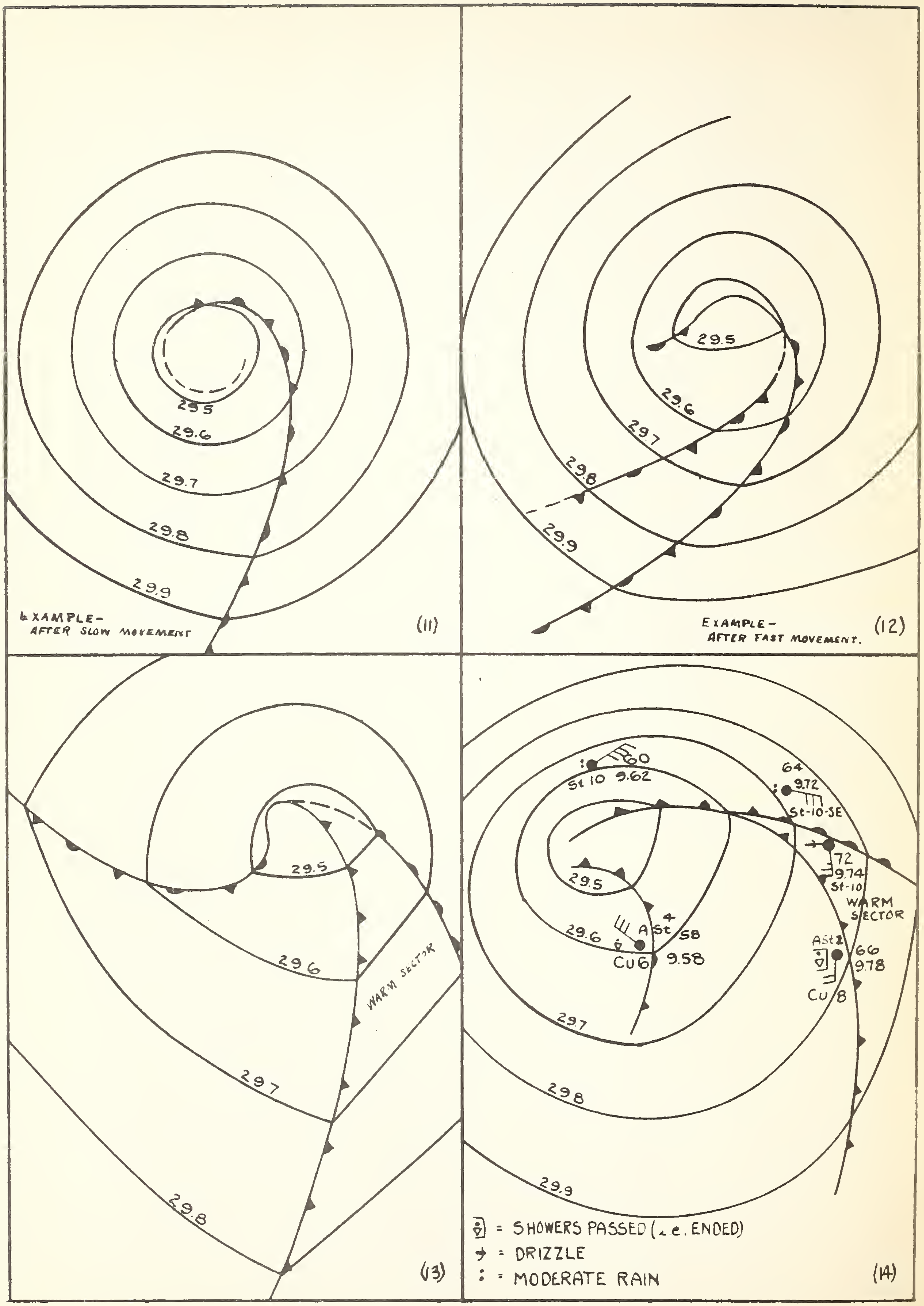
(10)

polar front ideas of cyclone structure. Discovered thru detailed studies of cyclones in recent years, it is now an important concept in the map analysis of the Norwegian school. A few other institutes now use the loop occlusion in their analysis, but comparison shows that with few exceptions (e.g. Prague, Breslau) the usage elsewhere does not conform to the principles found in the studies thru which such occlusions were discovered. Formations resembling these in figures 5 and 8 follow occlusion when the cyclone center moves toward the warm sector thereby placing the outer end of the occlusion in the easterly wind which reverses the original movement of translation and bends the occlusion back counterclockwise behind the cold front. The form and position of such a loop occlusion depends largely on the wind field. Disregard of the limits imposed by this field are a source of frequent errors.

105. Figures 7 and 8 show a new loop occlusion formed by a second bending back of the end of the occlusion thru the cyclone center. Under favorable circumstances several such loop occlusions may be formed. The conditions accompanying them resemble the conditions of secondary cold fronts. The loop occlusion however usually ends some distance from the center of the cyclone instead of continuing indefinitely as the general boundary of a new cold mass as does a true secondary cold front. The loop occlusions occurs much more frequently than the secondary cold front. It may be noted that this occlusion is actually a <u>loop</u> of the original occlusion in the center of the cyclone and that it is doubled gradually closer to the original occlusion until for practical purposes the two coincide within the center in the form in which they are usually diagrammed in the analysis.

106. The "eye" of the loop was formerly mistaken for a seclusion. The latter is now believed to occur rarely except when mountains bar the path of a current. The outer end of a loop occlusion usually lags behind the portion <u>nearer</u> the cyclone center (not <u>at</u> the center), a fact which applies to fronts in general.

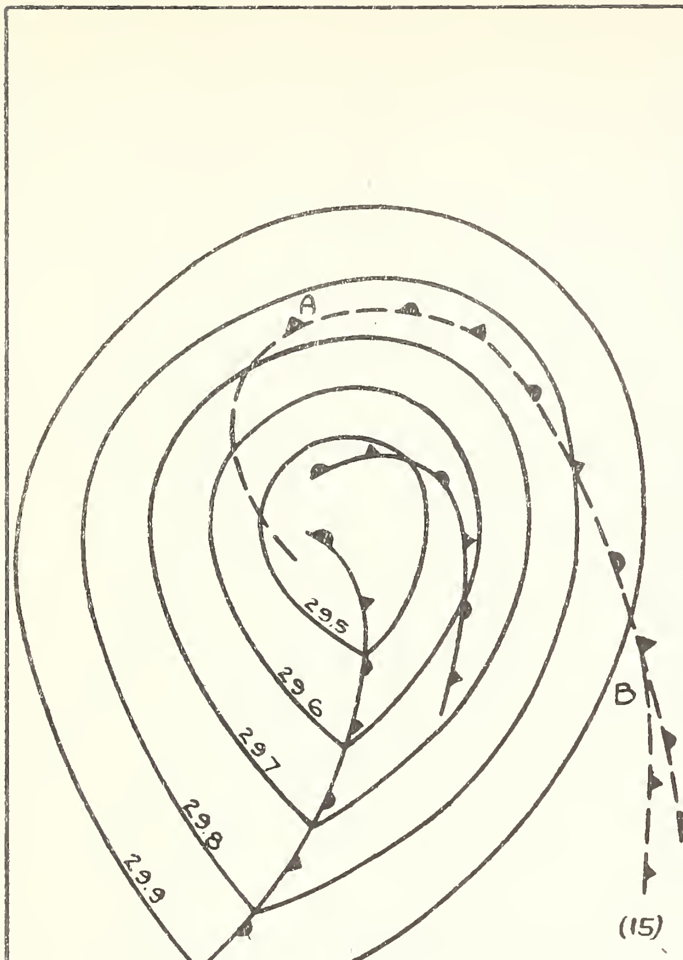
107. Figure 8 shows the original occlusion followed by two loop occlusions. Formerly these would have been incorrectly called secondary cold fronts. Figures 9 and 10 show the cloud and rain systems which are typical of the fronts shown in figures 6 and 8. These systems are in turn "symptoms" which aid in recognizing these front formations. The loop occlusion is complicated by processes other than the simple looping diagrammed here. Its development and behavior apparently depend somewhat upon the influence of an upper wave phenomenon associated with well defined fronts. For practical purposes however, the loop occlusion usually behaves in the manner illustrated. The approach of a second occlusion may cause the first to diminish rapidly in intensity, as does any change in field which attenuates the front and reduces the "upglide" movement.

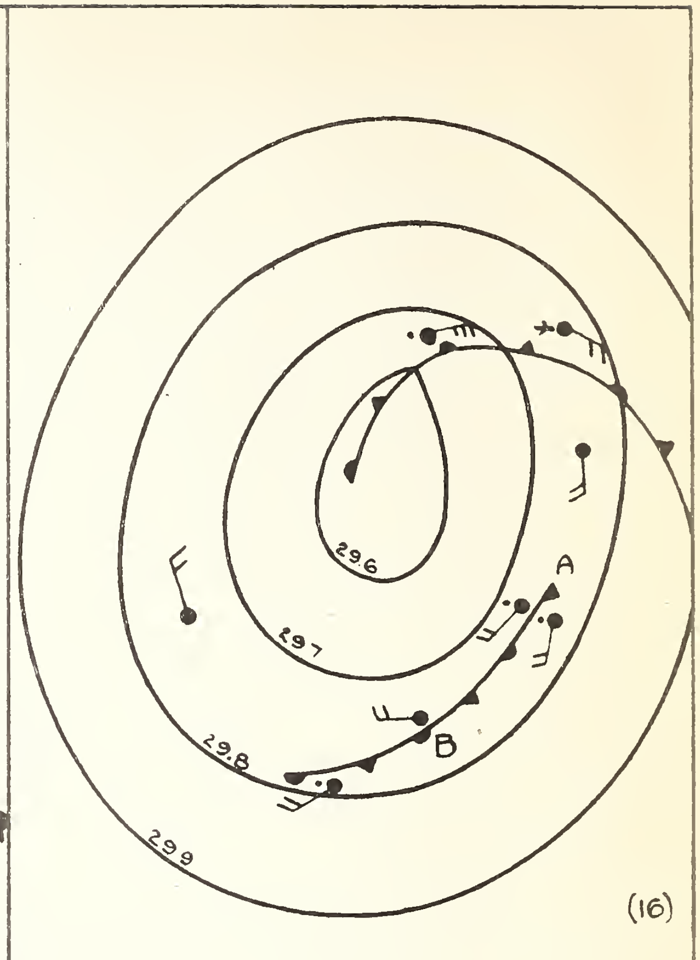

29.5
29.6
29.7
29.8
29.9
EXAMPLE-
AFTER SLOW MOVEMENT
(11)
29.5
29.6
29.7
29.8
29.9
EXAMPLE-
AFTER FAST MOVEMENT.
(12)
29.5
29.6
29.7
29.8
WARM SECTOR
(13)
60
St 10 9.62
64
9.72
St-10-SE
72
9.74
St-10
WARM
SECTOR
29.5
29.6
4
A St
58
Cu 6
9.58
A St 2
66
9.78
Cu 8
29.7
29.8
29.9
= SHOWERS PASSED (i.e. ENDED)
= DRIZZLE
= MODERATE RAIN
(14)

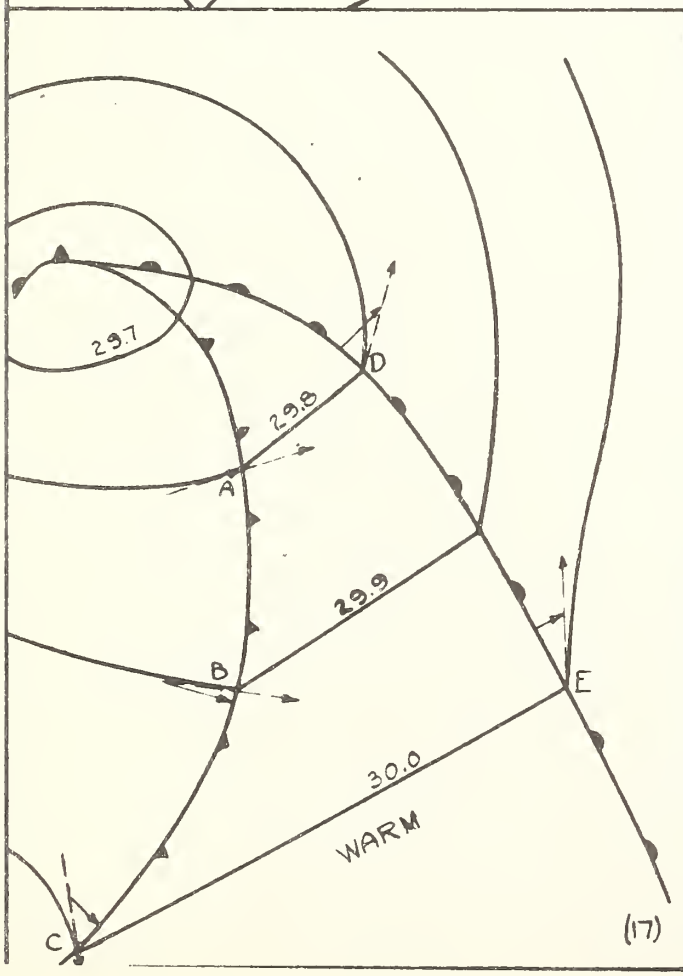
108. A very large cyclone tends to become stationary after occlusion. With its prominent fronts removed and only the cold mass remaining in the lower layers, the isobars and wind circulation become "circular". With no movement of the center, the formation of new loop occlusions is less probable, although not impossible as may appear on first consideration. (The upper wave phenomenon referred to may give such occlusions in stationary as well as moving cyclones). Figure 11 (eleven) shows a common arrangement of fronts in a large stationary occluded cyclone without a loop occlusion. Figure 12 shows a cyclone which has moved rapidly and has not been occluded long enough to become stationary. The original occlusion and two loop occlusions are shown. It is common observation that these occlusions occur much more frequently with moving cyclones than with stationary ones. Figure 13 shows a fast moving cyclone in which the lowest pressure has remained near the apex of the warm sector. Figures 11 and 12 in which the warm sector is too far south to be included in the figures are examples. Sometimes, however, the center moves rapidly southeastward and remains near the warm sector as shown in example 13. The straight isobars shown here are characteristic of the warm sector. Figure 14 represents a development similar to figure 13 but more advanced. The weather reports shown therein are typical of the "sectors" in which they are shown.

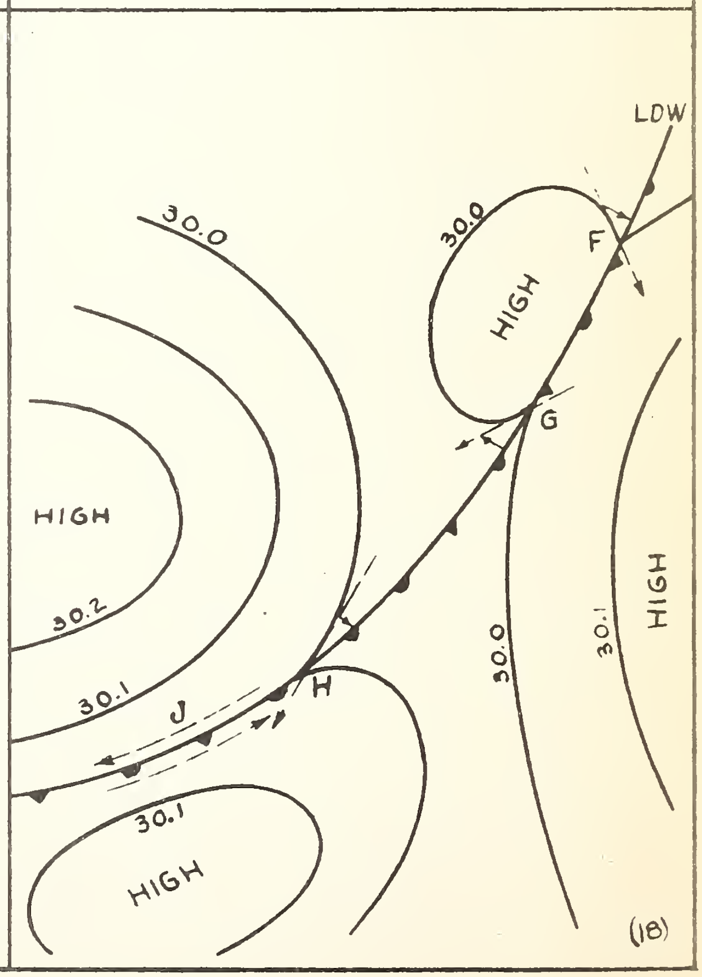
109. When the cold front is "quasistationary" in a situation somewhat like figure 14, conditions are often favorable for formation of a wave on the front. The wave moves toward the center of the cyclone and may cause a retrograde movement of the front, thereby widening the warm sector and giving new "life" to the cyclone. The wave may develop sufficiently to form its own loop occlusion and result in a complex structure at it nears the apex of the warm sector.

110. Figure 15 represents an occasional subsequent stage of occluded cyclones in which the low center deepens and moves toward the original warm sector or its occlusion so as to bring the isobars parallel to what remains of the original front, A-B. Such a front parallel to the isobars is difficult to discover. Since its system of clouds and precipitation may continue for a day or two, its recognition may be important in the forecast. The wind circulation sometimes causes attenuation on the front until it becomes practically separated and there remains no connection with its "parent" warm and cold fronts. Figure 16 represents another case of front parallel to the isobars, A-B. It illustrates how such a front with a narrow band of precipitation may give rain of unexpectedly long duration and heavy amounts at stations along the strip A-B, as


A
B
29.5
29.6
29.7
29.8
29.9
(15)


A
B
29.6
29.7
29.8
29.9
(16)

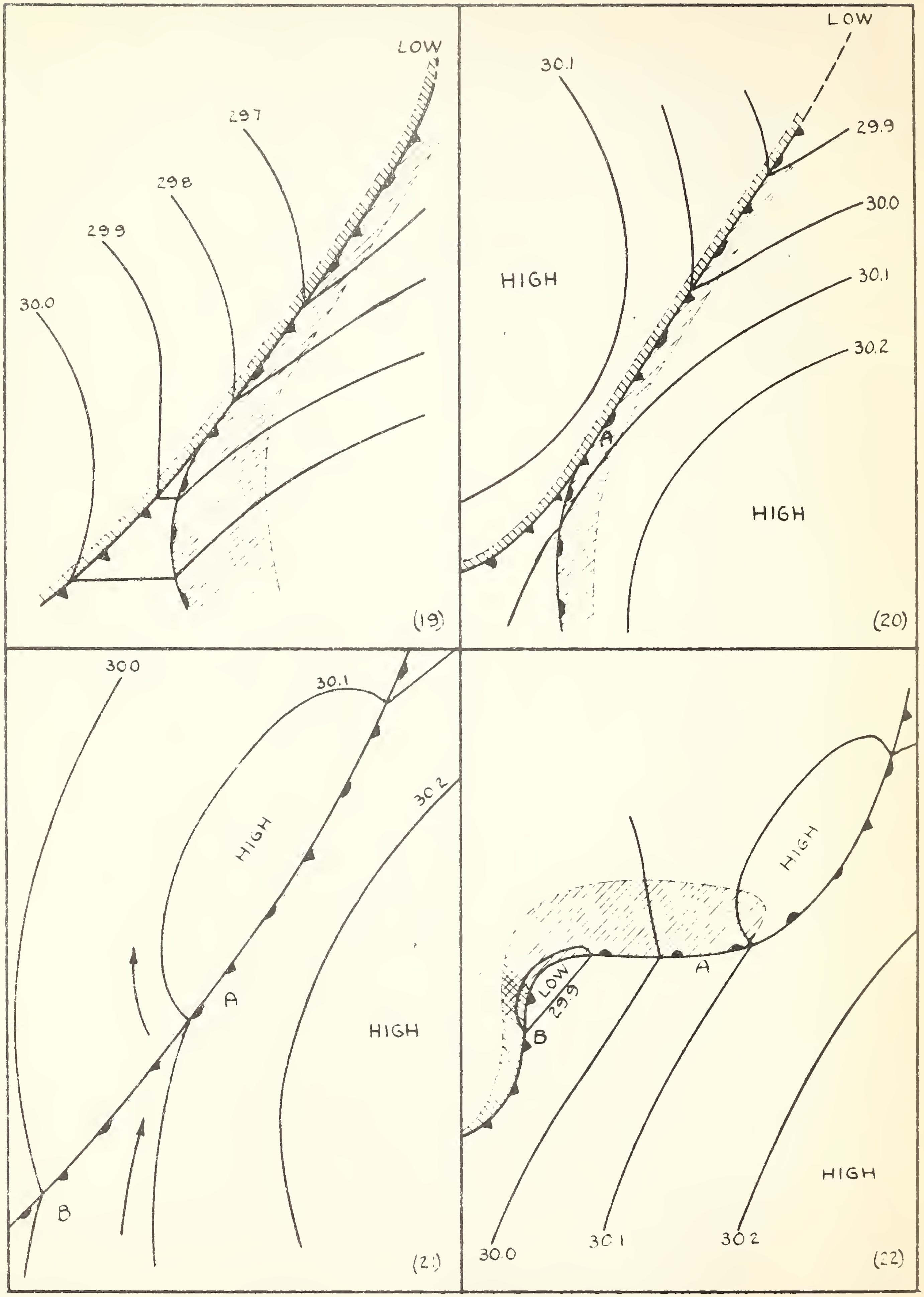

29.7
29.8
29.9
30.0
A
B
C
D
E
WARM
(17)


LOW
30.0
30.0
HIGH
F
G
HIGH
30.2
30.1
J
H
30.0
30.1
HIGH
30.1
HIGH
(18)

the front moves lengthwise northeastward. Such a front is usually identified through knowledge of its previous existence (historical sequence) and through the zone of frontal cloud forms and precipitation accompanying it. Also if wind reports to thirty two points are available, the front location is often marked by a slight convergence in surface winds.

111. The principle that movement of a front can be estimated from the component of the gradient wind (cold mass) perpendicular to the front is well known, but since this principle is often overlooked in published analysis of fronts, illustrations are given here. Its importance is shown by the fact that many of the difficulties in frontal analysis are the result of inattention to this principle. Figures 17 and 18 have the wind components indicated at certain points to illustrate the probable movement of the front. The dashed lines represent the gradient wind in the cold mass at a point close to the front. The full lines show the component perpendicular to the front. Both gradient velocity and direction are taken into account. At points A, B, and D, the wind direction is almost perpendicular to the front and the velocity is fresh. The movement of the front is therefore large. At C, E, F, G, and H, the direction is far from perpendicular, and in some cases is almost parallel to the front. Front movement is therefore slight, especially where velocities are small. Similar cases are often found over southeastern United States. A front may lie thus for several days with only a few miles movement daily. It may be incorrectly moved off the map in the analysis. Later, when reinforced by a change in wind and pressure fields, rain may develop, the source of which is thus lost. Point "J" shows a place where the front is quite parallel to the isobars and therefore has no appreciable broadside movement. It may remain inactive in such a position for days, and later become important in the forecast.

112. Fronts which pass a region, become stationary and then return, reinforced, as result of a wave disturbance or a general change in the pressure field are a source of "surprise" bad weather. This occurs most frequently when an occluded front is moved to the western edge of the tropical high pressure areas. It also occurs when a front stagnates in a position parallel to the isobars especially with anticyclonic isobars on its opposite sides (i.e. opposite winds). Figures 19 to 22 illustrate this. Figure 19 shows an occluded front moving eastward, the "parent" warm and cold fronts to the south. Its moving is slow because the winds on its opposite sides are almost parallel as shown by isobars. Figure 20 shows the front at a later stage when its lower part has become stationary for the reasons stated. This sketch covers a region farther south than the preceding sketch 19, and the apex of the warm sector is again shown. The isobar, 30.1, indicates that the southerly warm current continues to ascend over the colder wedge

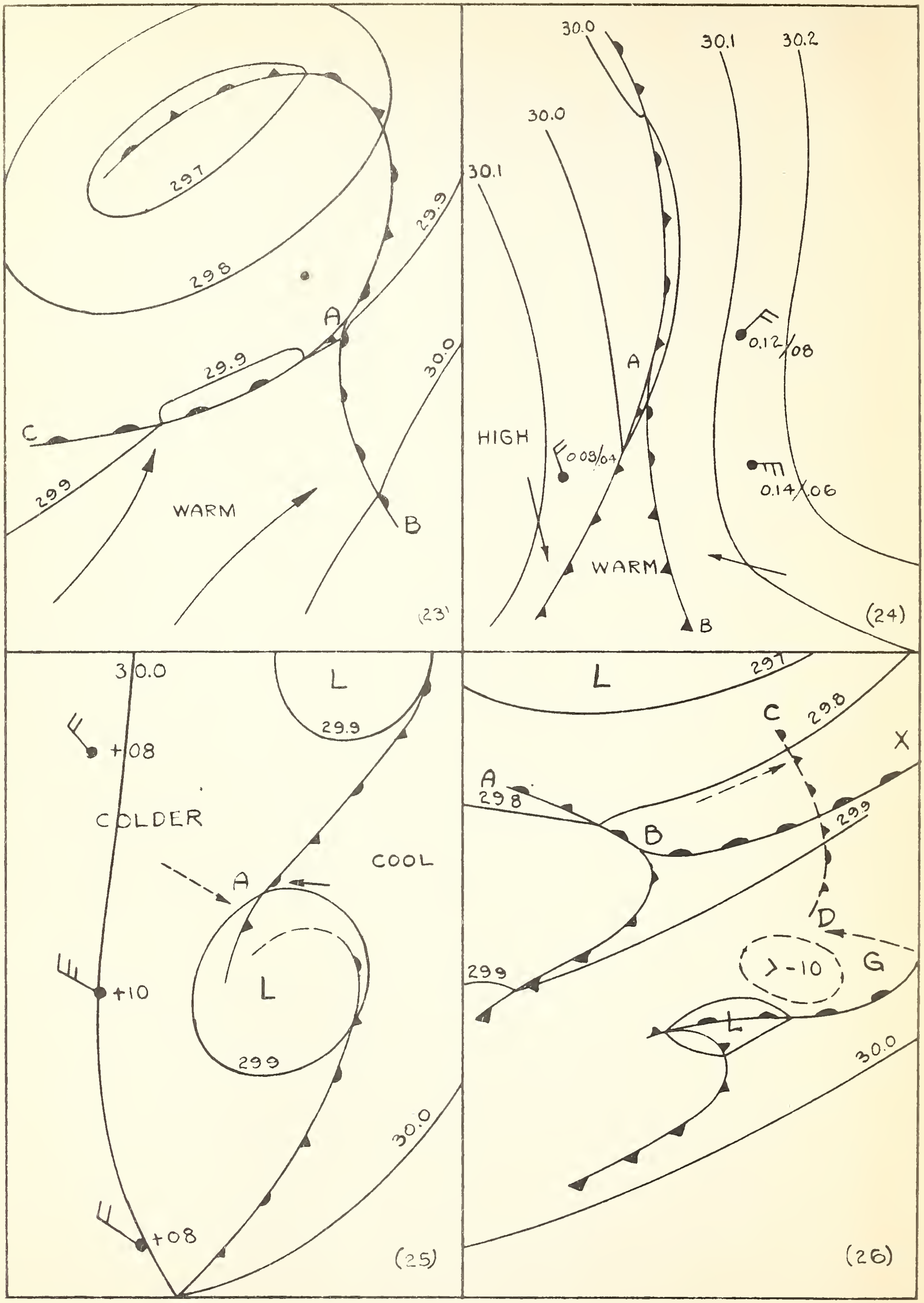


LOW
29.7
29.8
29.9
30.0
(19)
LOW
30.1
29.9
30.0
30.1
30.2
HIGH
A
HIGH
(20)
30.0
30.1
30.2
HIGH
A
HIGH
B
(21)
HIGH
LOW
29.9
A
B
HIGH
30.0
30.1
30.2
(22)

of the occlusion north of the warm sector and that formation of clouds and perhaps precipitation along the front is still going on. The forecast must take this into account because in vicinity "A", fig.20, where the front is stationary, the clouds and rain may continue for many hours while areas short distances on either side have clear weather.

113. In figure 21 the gradient over the lower portion of the front has reversed direction as shown by the isobars and the arrows denoting the gradient winds from a outherly direction. The front has started to move back. Over the northern half the front is stationary. At this stage clouds and precipitation previously occurring along the front may have disappeared altho it is usual for a narrow strip of typical occlusion clouds to remain along the front. If, as is probable, the southerly current on the right side of the front is a warm air mass, the occlusion along portion A-B where movement northward has begun, quickly takes on the character of a warm front. The altostratus cloud sheet extends rapidly and rain sets in, usually aided by development or approach of a wave disturbance along the front as shown in figure 22. Such a disturbance, forming on some stationary part of the front, where the wind discontinuity is suitable would, in the case shown, move northward. Its approach affects the wind and pressure fields so as to further develop the warm front structure and, in its "rear" (actually the forward surface of the cold mass wave) changes the front into an active cold front. The wave may continue along the front as a true wave, the front behind it settling back into its former position in conformity with the general pressure field until a new wave comes along. Often, however, wind and temperature fields are favorable for development into the ideal moving cyclone. In any case, it is plain that the movement of the front results in bad weather (clouds and rain) over an area northward or westward of it, that is, over an area which the front had left behind on its eastward movement several hours or days before, and where the weather had cleared. It is also plain that in the recognition of such developments lies the differences between an incorrect forecast of clear weather, and a correct forecast of rainy weather for the region effected. Sometimes this region is very broad. (For examples - see U.S. Weather Maps January 7 to 8, 1932).

114. As indicated above, changes in the general pressure field due for example to development or arrival of a new cyclone over adjacent regions or to pressure changes originating in the substratosphere, etc., often change the gradient and modify the character of fronts. A cold front may thereby have its direction of movement reversed and become a warm front. An inactive front may be reinforced, and vice versa. Figures 23 and 24 illustrate two cases which are somewhat unusual and confusing as to front movement. In 23, front A-C which has been a cold front is now under influence of the gradient ac-


29.7
29.8
29.9
A
29.9
30.0
C
29.9
WARM
B
(23)
30.0
30.1
30.2
30.0
30.1
A
0.12/08
HIGH
0.08/04
0.14/06
WARM
B
(24)
30.0
L
29.9
+08
COLDER
COOL
A
L
+10
29.9
30.0
+08
(25)
L
29.7
C
29.8
X
A
29.8
B
29.9
D
29.9
> -10
G
L
30.0
(26)

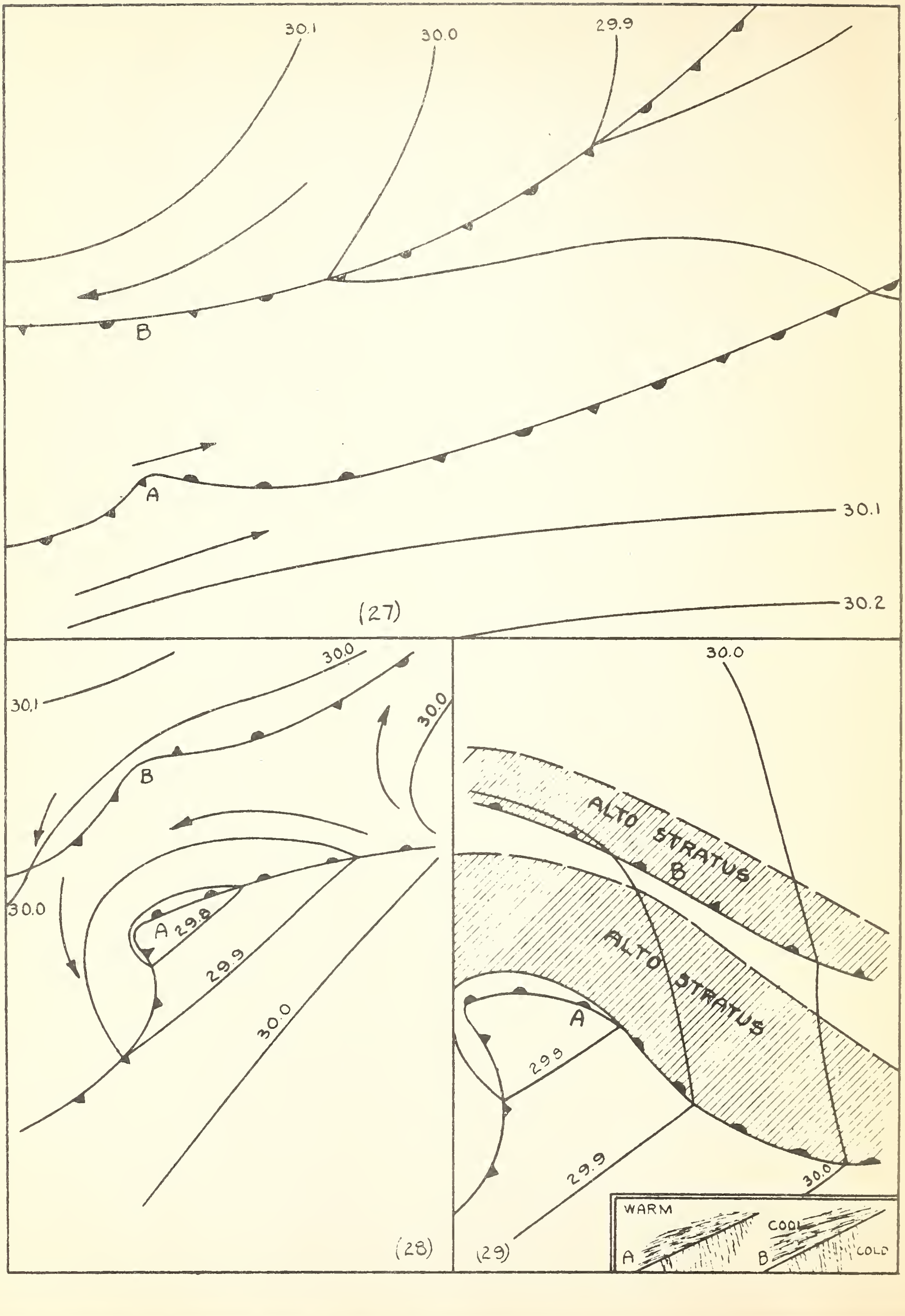
companying the occluded low from the northwest. In its lower portion, it is moving northward as a warm front. The warm front is still acting normally. Thus the "warm sector" has "two warm fronts". This gives in effect a widening warm sector, an infrequent development. When the warm sector widens it is usually, as here, in a "stationary" cyclone, and rarely in a moving cyclone.

115. Figure 24 illustrates the opposite situation - a warm sector, with cold fronts on two sides. A-C is the common cold front. The HIGH on the left has increased. The easterly winds from it are being accelerated, (blowing across isobars), the pressure and wind not yet having reached a balanced condition. The front A-B is therefore moving westward as a cold front. This movement is apparently against the gradient. In such cases, the front usually moves unexpectedly. This behavior is infrequent, and can usually be recognized by the very decided fall in temperature and great rise in pressure (three hour tendencies) on the cold side of the front.

116. When a weak cyclone has a large movement of translation due to general circulation, a portion of a front which appears from the surface gradient to be a warm front may be acting as a cold front. The portion marked "A", figure 25 is an example. The cyclonic circulation carries the front to the left but the entire system is moving rapidly to the right, giving the front an actual movement to the right despite the local gradient. Such a case can usually be recognized in the large pressure tendencies and "accelerated" winds on the cold side.

117. Rapid increase in a cyclonic circulation greatly modifies the surrounding gradient and therefore the movement of nearby fronts. For example in figure 26 the occluded front A-B moves rapidly northeastward if there is no change in the pressure field. Its influence in the weather at X will be considered in the forecast. With rapid development of the wave to the south, the resulting cyclonic gradient in region G is reversed and the southern portion of the front A-B retarded so that it takes a position something like C-D. The front not only fails to reach X but the divergence and subsidence in this region between the two cyclonic systems probably will give fine weather in region "X". (The pressure field in figure 26 illustrates conditions for front position A-B, and not conditions after development of the wave which results in subsequent position C-D).

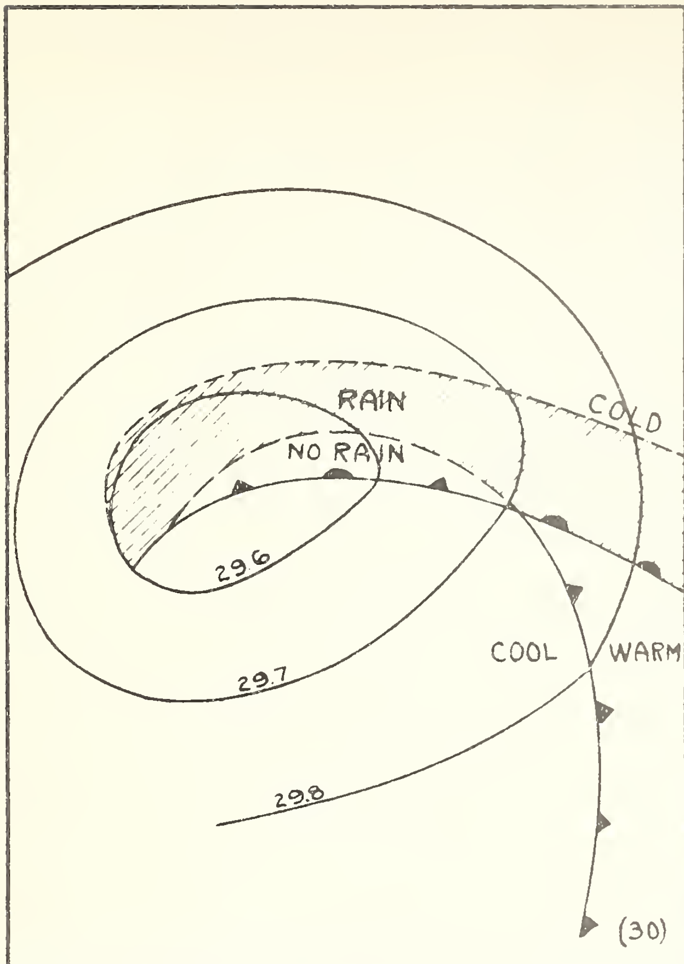
118. An old front which has become "stationary" and inactive often resumes importance in the manner illustrated in figures 27 to 29. The success of the Bergen school in forecasting rapid changes in weather on the basis of very few ocean reports is due in part to the attention given to probable behavior of such fronts. Figure 27 illustrates a common distribution with two old occluded fronts left

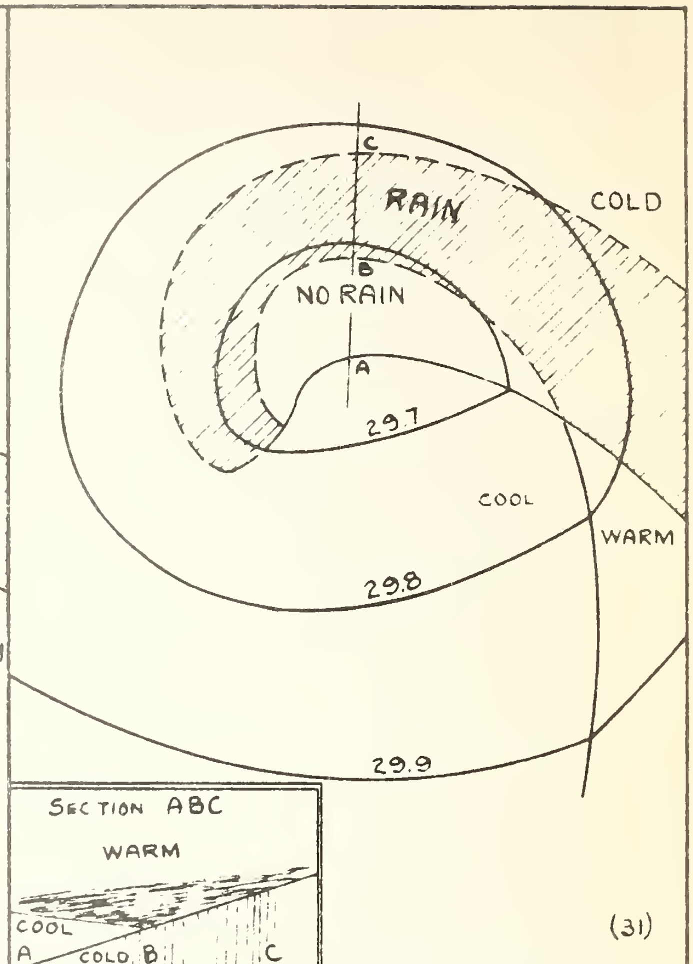

30.1
30.0
29.9
B
A
30.1
30.2
(27)
30.1
30.0
30.0
B
30.0
A 29.8
29.9
30.0
(28)
30.0
ALTO STRATUS
B
ALTO STRATUS
A
29.9
29.9
30.0
(29)
WARM
COOL
COLD
A
B

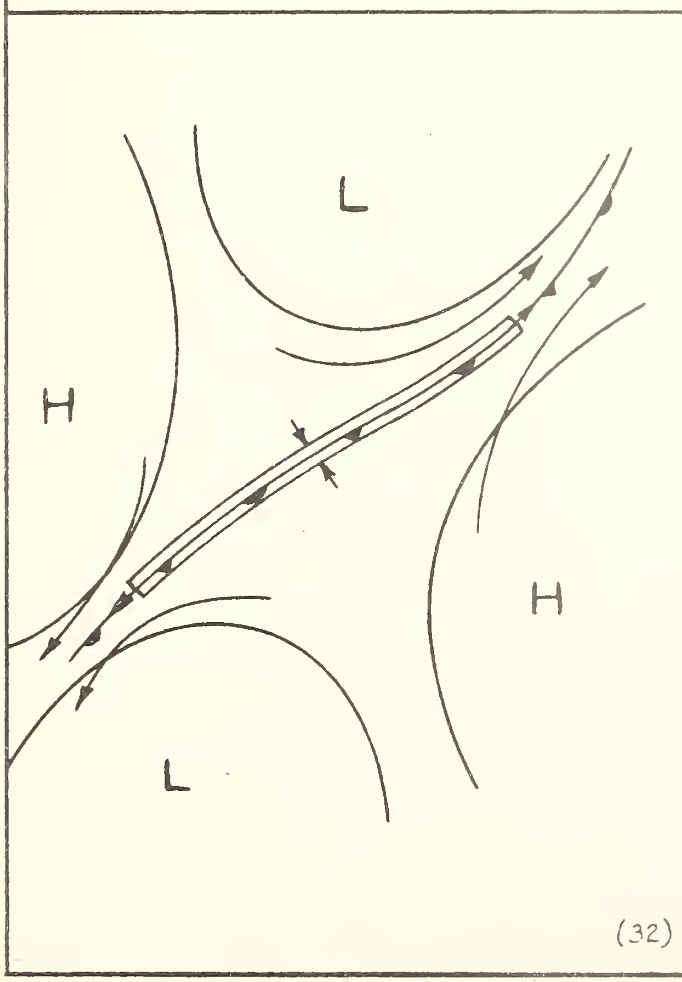
behind by cyclones which had passed off the map. The fronts are approximately parallel and quasi-stationary. With suitable differences in wind velocity and on the opposite sides of such front, a wave is likely to develop as at "A", figure 27. If development continues as in figure 28, the northward component of the gradient in front of the wave A, and the southward component behind it tend to distort the field around region "B" and set up a system on the northern front homologous to that around "A". This forms a wave on "B". The two systems may develop together and the resulting structure become difficult to recognize unless traced from the beginning. In regions of sparse reports, the pressure tendencies, clouds and rain resemble those for a single north-south occluded front and thru A-B. The single occluded front would call for a forecast of wind and weather different from that required in case of two waves at stages subsequent to illustration, fig. 28. This subject has been amplified by T. Bergeron, reference ________.

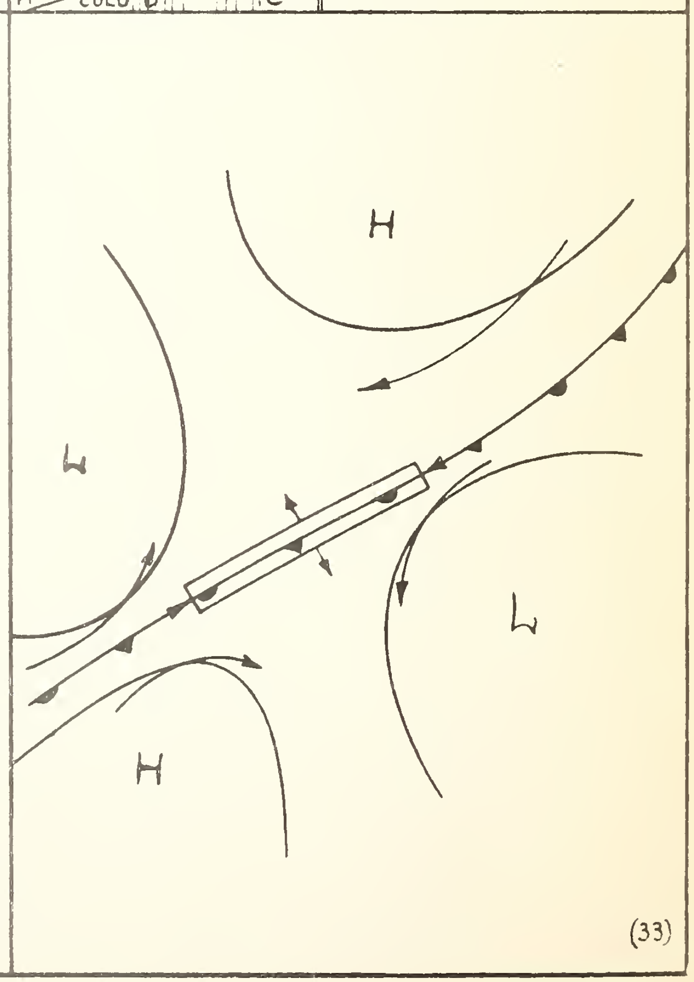
119. Pressure field usually reveals whether winds are suitable for wave formation. Obviously, certain conditions such as divergence of the wind currents on opposite sides of the front are favorable. Divergence may be shown by wind observations or by the existence of two distinct katallobars.

120. Figure 29 illustrates a different kind of development which takes place in connection with two "old" fronts when general distribution is favorable. It may be regarded as a development farther to the west along the two fronts in figure 28. When a well defined cyclone is formed on the more southern front, its wind system renews the "upglide" motion on the frontal surface of the northern front and a wide spread warm front system develops. The result of it is an apparent rapid extension of warm front clouds and rain, perhaps several hundred miles in advance of A, figure 29. This structure may be recognized at its start by the rainless zone between the two fronts. Sometimes the zone just south of the northern front is cloudless for a time. If the cloud and rain areas of the two fronts have already merged, the "double front" structure is often shown by a zone of lighter rain between the two areas of heaviest rain as illustrated at B in the vertical section thru the fronts, inset, figure 29. Double fronts like these are the usual cause of very wide rain areas. Occasionally there are three fronts in such areas. Knowledge in the position of old fronts in a region ahead of a cyclone is thus of direct use in forecasting development of the rain area. A front which has been diffuse and inactive for several days with no cloud reports, etc., to identify it is still a zone favorable for "upglide" motion and rapid formation of clouds and rain if wind and pressure fields again become favorable. Inactive fronts such as this can usually be located on the map as long as necessary by use of principles outlined in paragraphs on front identification and location (gradient movement, especially). (See U.S.Map, Dec. 8-9, 1931).


RAIN
NO RAIN
COLD
29.6
29.7
29.8
COOL
WARM
(30)

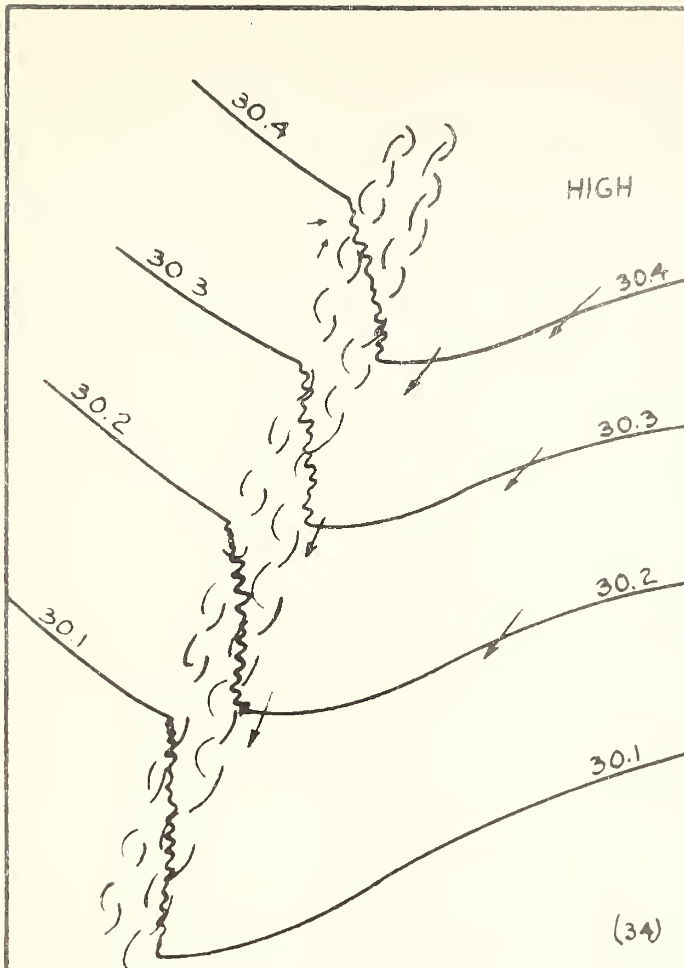

C
RAIN
COLD
B
NO RAIN
A
29.7
COOL
WARM
29.8
29.9
SECTION ABC
WARM
COOL
A
COLD
B
C
(31)

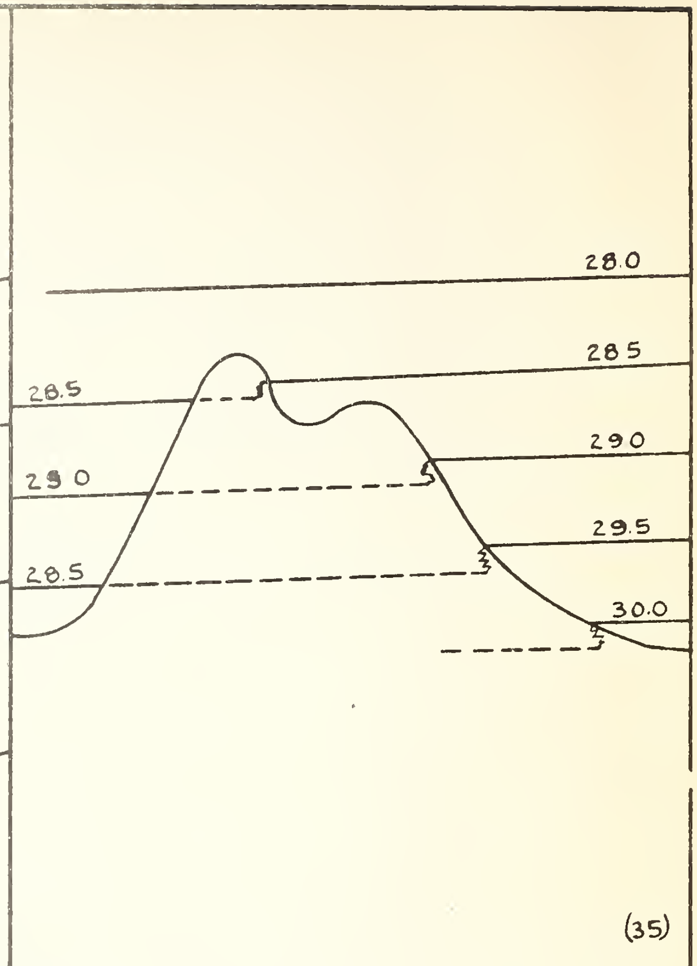

L
H
H
L
(32)

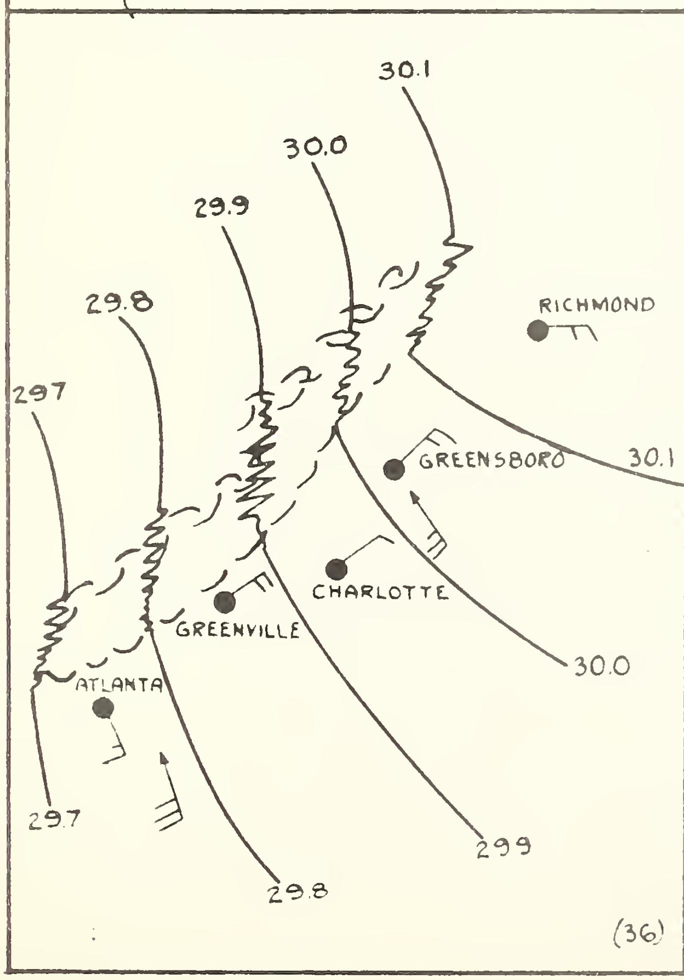

H
L
L
H
(33)

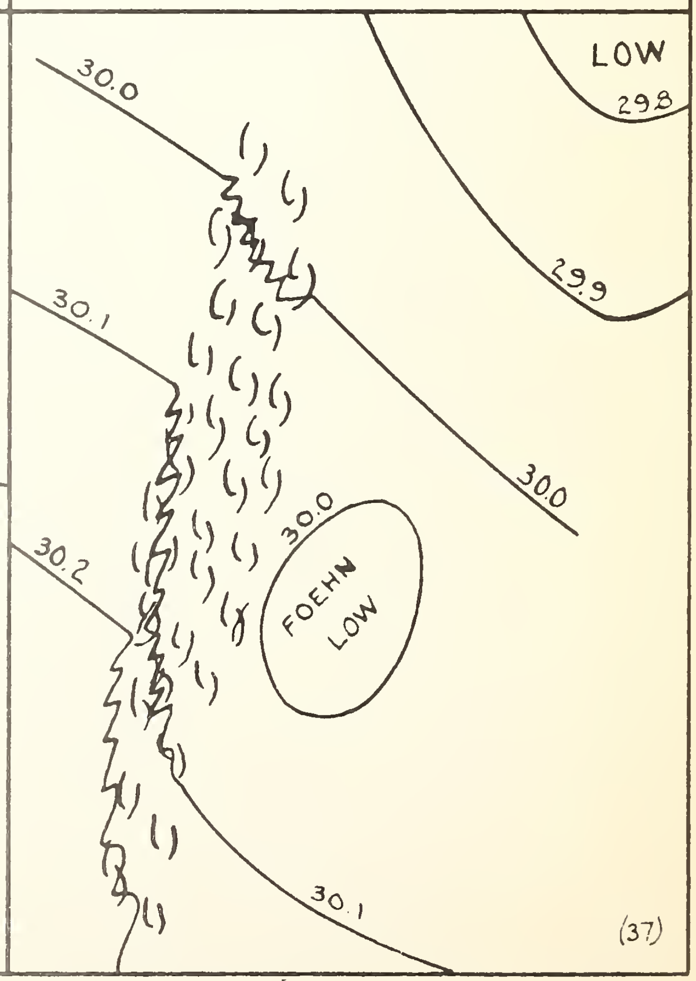
121. When a rain area becomes farther separated from its occluded front from map to map, there is usually an upper front. The upper front advances as the telescoping movement of the two fronts (former warm and cold fronts) continue. Figures 30 and 31 illustrate this formation in the case when the air following the cold front is not as cold as the air preceding the warm front. These stages (figs 30 & 31) may be considered to follow the occlusion stage illustrated in figure 14 (disregarding for this purpose the temperature distribution in that figure). Thus, if the "cold" front air mass continues ascent on the warm front surface, the cold front, now an upper front, advances ahead of the warm front. If conditions are such that ascent ceases over the former cold front surface, the rain area may be bounded by the upper front as in figures 30 and 31. (See vertical section, inset fig. 31). When the upper front is significant, as here, its position is shown by dashed lines on the map coinciding with its projection on the ground. If the occlusion is of the cold front type (colder air in rear), the upper front obviously falls behind the surface occlusion as the former warm front ascends on the cold front surface. The rain may then be entirely in the rear of the upper front. The passage of an upper front can often be discovered in the barometer tendencies. The characteristics are similar to those for any front, but usually less distinct. The Bergen school is very successful in identifying passage of expected upper fronts in the behavior of the local barograph trace, in this way often verifying the front structure found on the map.

122. Figure 32 illustrates a situation favorable for increase in sharpness of a front. Most of the cases of true frontogenesis observed on the weather map are in such situations. The wind distribution is favorable for "stretching" of the frontal zone lengthwise, thereby making it narrower and the temperature discontinuity sharper. The wind is also favorable for bringing air from a colder source into a position close to air from a warmer source, further sharpening the discontinuity, or tending to build up a discontinuity (frontogenesis) if none existed before. (See U.S. Map, Jan. 3-4,1931). To be effective such a "neutral zone" must be stationary or almost so. Conversely, in figure 33, a front lies in a region of diverging winds where the frontal zone would tend to become wider and the front diffuses. The relation of these formations to the well known "saddle" and wedge is apparent. In general it is useful in determining the possible sharpening of one or the other of two nearby fronts to consider which has a pressure field favorable for narrowing of the frontal zone. For example, if one front does show convergence of the opposite sides, say SW vs. NW winds, while the other shows no tendency to wind contrast, perhaps southwest winds are on both sides, the latter usually loses importance.


30.4
HIGH
30.3
30.4
30.2
30.3
30.1
30.2
30.1
(34)


28.0
28.5
28.5
29.0
29.0
29.5
28.5
30.0
(35)

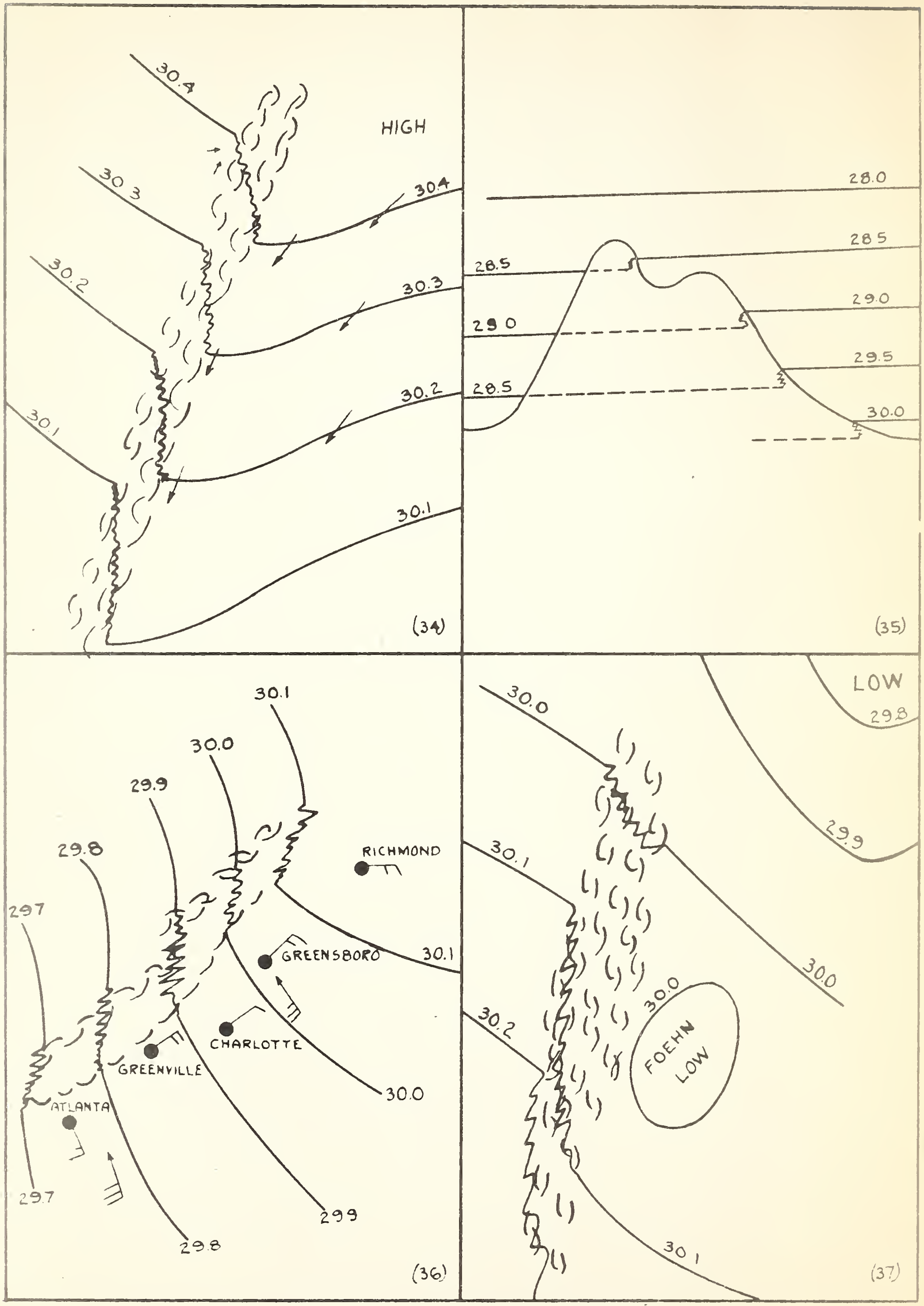

30.1
30.0
29.9
29.8
29.7
RICHMOND
GREENSBORO
30.1
CHARLOTTE
GREENVILLE
ATLANTA
30.0
29.7
29.9
29.8
(36)


LOW
29.8
30.0
30.1
29.9
30.0
30.2
30.0
FOEHN LOW
30.1
(37)

123. A few examples of pressure fields modified by mountain ranges are shown in figures 34 to 37. (These features are included here because their importance is overlooked in many published analysis). Such features are shown as accurately as practicable in order to assist the forecaster in quickly recognizing whether reports are representative or have been modified decidedly by mountains; also to assist him in recognizing probable effect of mountains on movement and character of fronts. Relatively slight slopes cause more important changes in weather elements, a fact which enters into interpretation of temperature, pressure, wind, clouds and rain (form and amount). Figure 34 illustrates a mountain range acting as a barrier to a cold air mass which has moved southwestward along the east side of the range. The break in the isobars where the mountains have interrupted the flow of air is shown by the zig-zag lines. Obviously, pressure west of the mountains is lower because of the mountain barriers. The wind is deflected from northeast to northnortheast. The usual balance between the pressure gradient and earth's deflection "force", etc., is interrupted by the mountains and the wind blows across the isobars (is accelerated). If a front exists in such a pressure field, it is moved rapidly southward with the air mass along the eastern edge of the mountains.

124. If a cold mass is sufficiently deep that its cold front is pushed across a mountain range, there may be considerable over running of the "cold" mass before it penetrates to the surface (due to foehn heating, etc.). Surface winds may therefore remain representative of the warm mass for some time after the front has passed aloft. Several factors complicate such a situation, one being the effect of the mountains in causing an upper wave as mentioned elsewhere. The result is that a cold front although retarded in getting across the range tends to advance very rapidly after it gets across until it overtakes its old trough. Again, the blocking of a cold front by a mountain range may allow a warm front in the lee of the mountains to remain stationary for a long period, until a cold front eventually arrives and forces it to move. The effect of high headlands on winds is well known but easily overlooked in the forecast unless topography and resulting true isobars are plainly shown. The "corner effect" of a high cape in causing gale winds with the general gradient only "moderate to fresh" is especially noteworthy in stable air masses (warm). A cape or mountain may also cause sufficient divergence in winds from some directions to give subsidence in higher layers and local clearing of the clouds. These important facts are brought to attention at once when the topography and the modified pressure field are shown on the map.

125. Figure 35 shows diagrammatically a vertical section thru an air mass held back by a mountain range. The lines represent the intersections between a vertical plane and the isobaric surfaces.

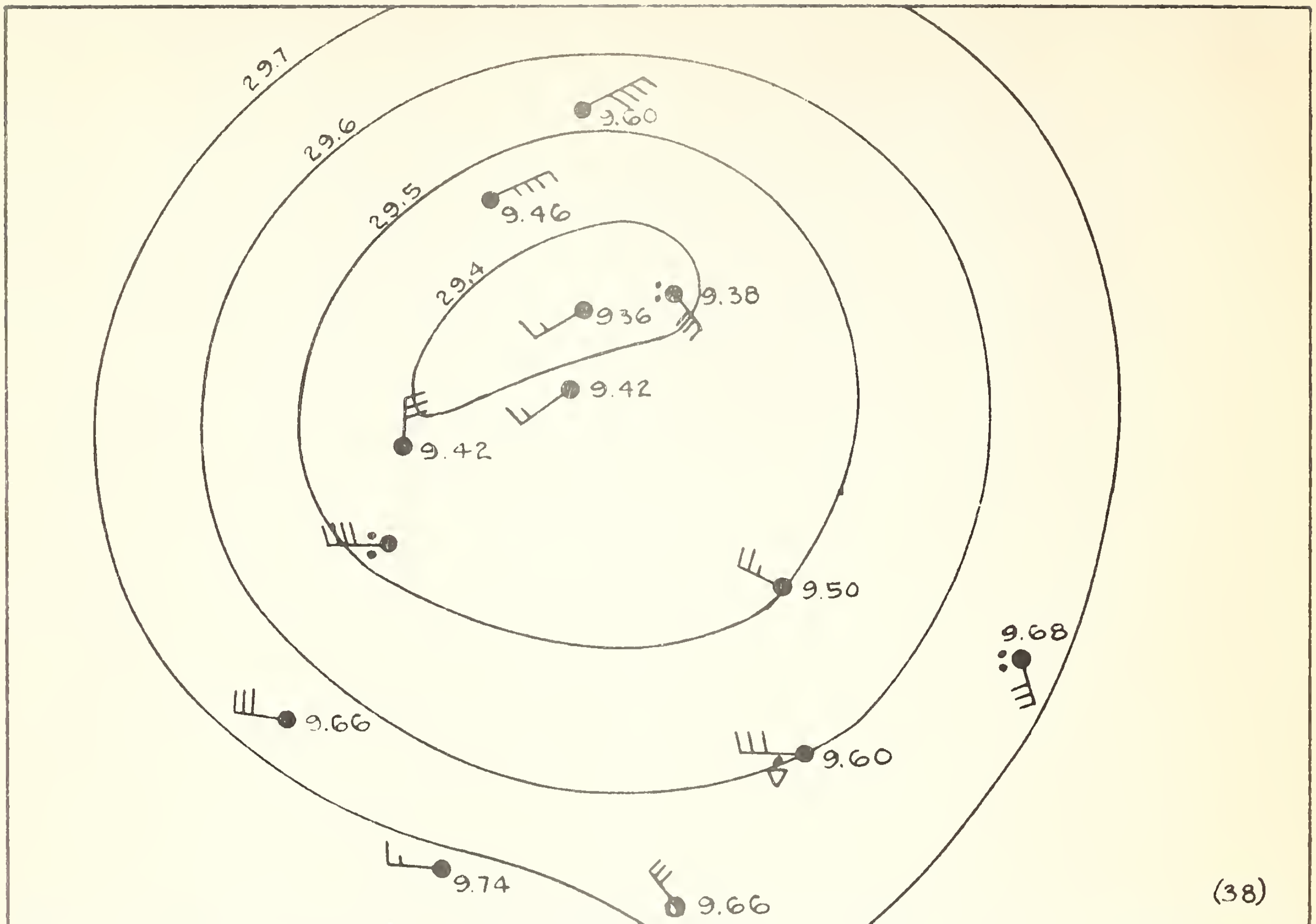

30.4
HIGH
30.3
30.4
30.2
30.3
30.1
30.2
30.1
(34)
28.0
28.5
28.5
29.0
29.0
29.5
28.5
30.0
(35)
30.1
30.0
29.9
29.8
RICHMOND
29.7
GREENSBORO
30.1
CHARLOTTE
GREENVILLE
ATLANTA
30.0
29.7
29.9
29.8
(36)
LOW
29.8
30.0
29.9
30.1
30.0
30.2
30.0
FOEHN LOW
30.1
(37)

126. Figure 36 shows an example of mountain effect in southeastern United States. (Dec. 31, 1931 - 0800). Weather Bureau stations nearest the mountains reported fresh northeast winds while the pressure gradient called for east and southeast winds. The existence of the gradient is verified by the pilot balloon observations at two of these stations which show fresh southeast winds at eight hundred meters altitude (see arrows near Atlanta and Greensboro). At Atlanta, where the mountains to the westward are mostly less than 1000 feet high, the surface winds agrees more closely with the gradient. The weather on this date also showed the effect of the mountains, a zone in the lee of the highest mountains reporting considerably less rain in amount and duration. A down slope wind with descending component of only thirty feet per mile reduces the upgliding motion in many warm fronts sufficiently to stop the formation of rain without regard to further effect of heating in the lower layers and evaporation of falling rain drops. (See U.S. Map 12/31/1931 showing interruption of the rain area (Lexington, Nashville, Springfield) in lee of mountains).

127. Another foehn effect which enters into interpretation of reports is the selective evaporation of rain drops. The smaller drops evaporate but the larger drops reach the ground, thus giving alto-stratus rain the appearance of light <u>showers</u>.

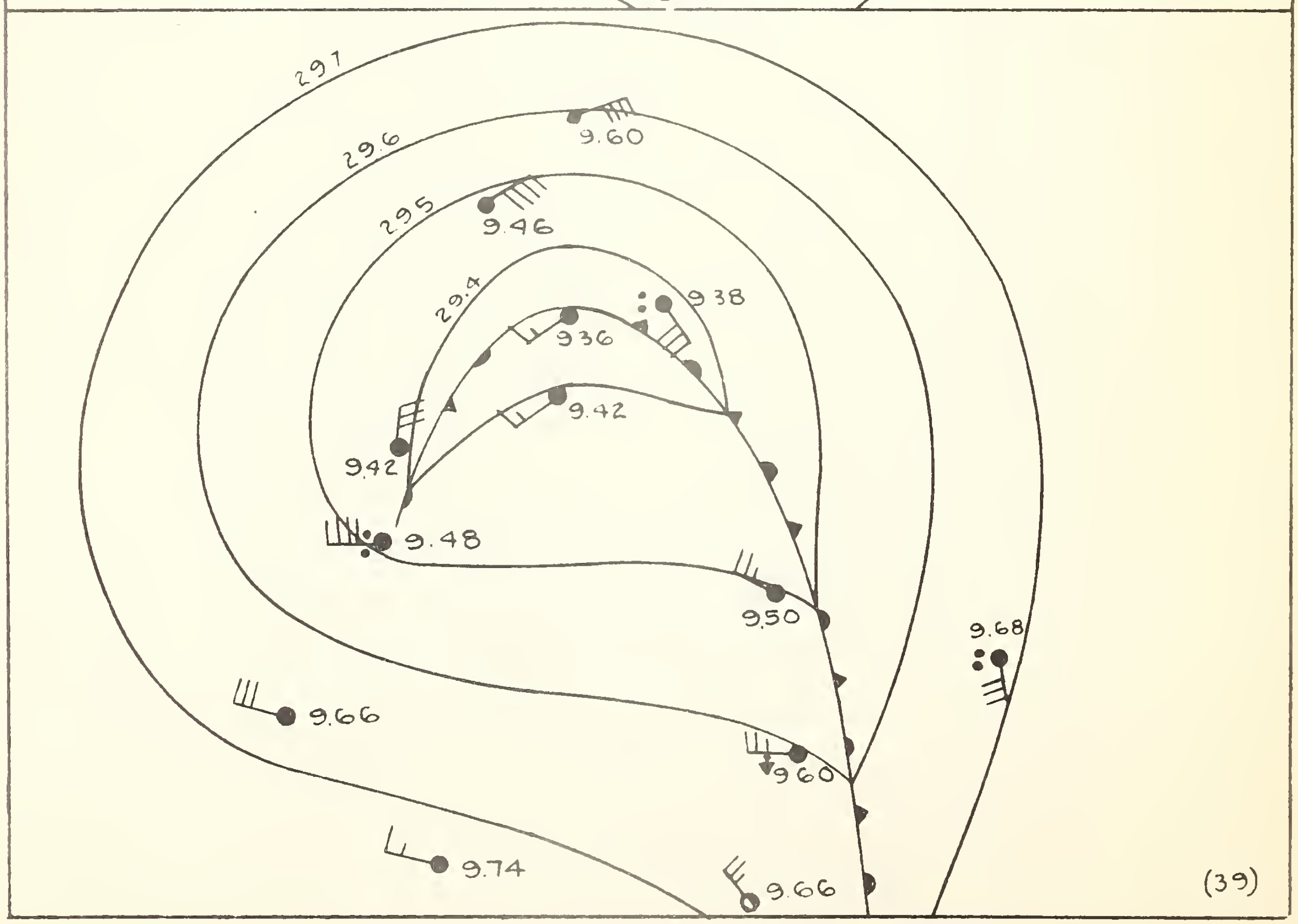
128. Obviously, topographical influences like these must be taken into account to avoid erroneous conclusions as to location and character of fronts. There are numerous stations where topography or nearby buildings etc., materially modify true representative conditions. A contour map quickly shows why winds reported from Scranton, Ft. Smith (Arkansas), Cheyenne, and many of the Pacific and Rocky Mountains stations are often misleading.

129. The probably of errors in barometer reports from mountain stations as result of temperature factor in reduction to sea level is kept in mind with analysis. Figure 37 illustrates the well known foehn effect which comes in for due consideration during analysis. Lows such as this which often appear on the lee of mountain ranges are significant chiefly as a frequent source of incorrect analysis. They often lead to wrong conclusions as to the origin of a cyclone and the movements of fronts. The local wind distribution accompanying a foehn low is mistaken as evidence that a front lies there. The probable error is to mistake a foehn low for an active moving cyclone. The winds which give rise to the foehn often occur with an approaching depression. If the foehn low is mistaken for the true travelling cyclone, the forecast relating thereto is based on a fictitious movement and structure and therefore is incorrect. It is interesting to note that the influence of such a forecast is not limited to continental areas, but often applies to coastal and



29.7
29.6
29.5
29.4
9.60
9.46
9.38
936
9.42
9.42
9.50
9.68
9.66
9.60
9.74
9.66

(38)



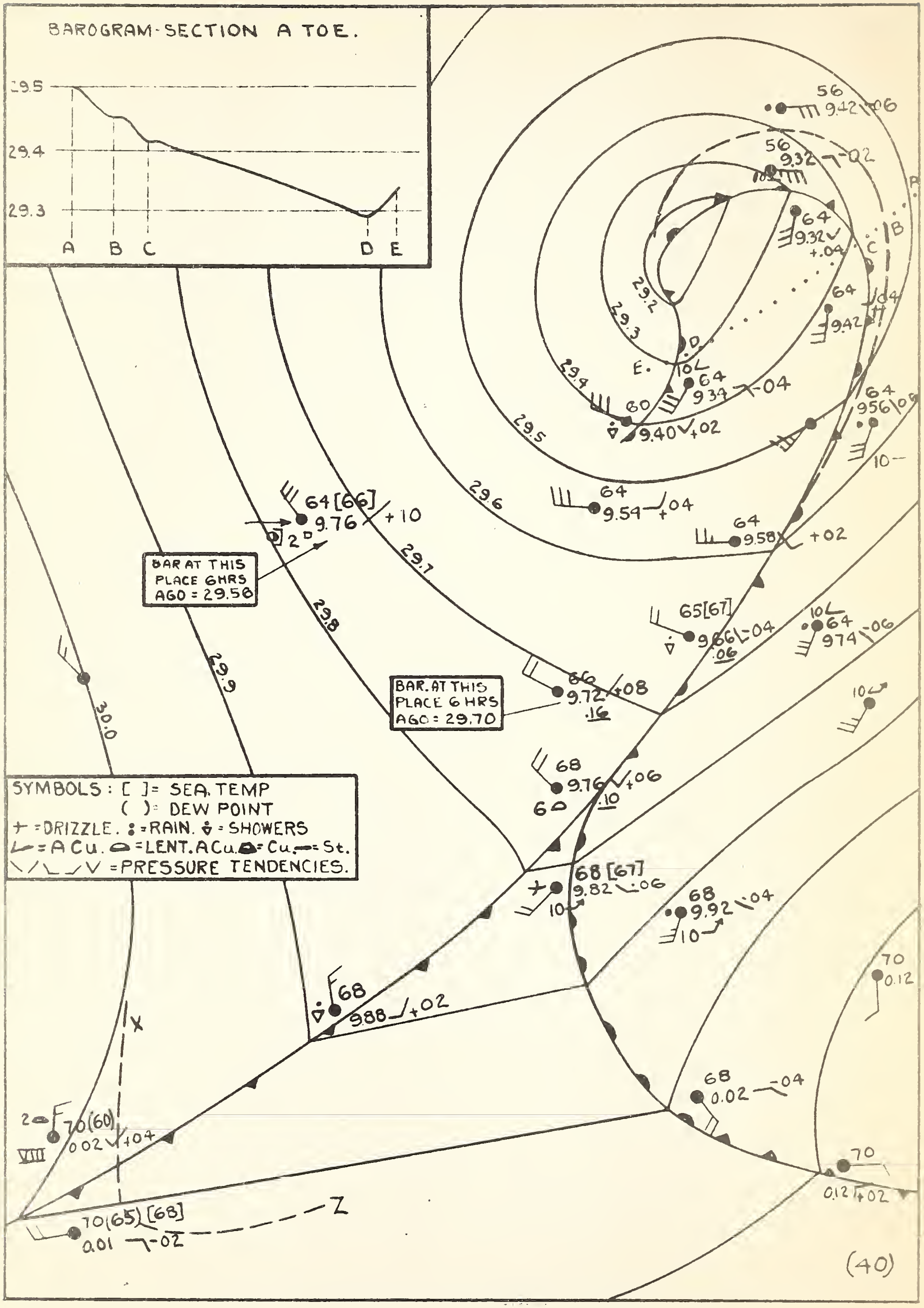
29.7
29.6
29.5
29.4
9.60
9.46
9.38
936
9.42
9.42
9.48
9.50
9.68
9.66
9.60
9.74
9.66

(39)

ocean areas a considerable distance from mountains. For example, a forecast for the Atlantic Coast sometimes depends upon analysis of a low in the lee of the Appalachians - whether a foehn low, or a new and rapidly developing secondary cyclone. Usually it is possible to distinguish between the two by a study of topography and accompanying weather, winds and temperature, including temperature changes. These elements show whether foehn effect is probable in the given case. Lenticular clouds, local clearing, and unusual temperature rise confirm foehn conditions.

130. A foehn low does not necessarily remain only a lee effect if temperature field and other conditions are favorable it develops into a true moving cyclone with fronts. The probability of such development is usually indicated in the attending distribution of weather elements. Development is comparatively slow. Numerous other features aid in recognizing individual cases (Brooks,MWR-1922). In the infrequent cases when "present" indications are inconclusive, definite decision is usually (not always) possible on subsequent maps.

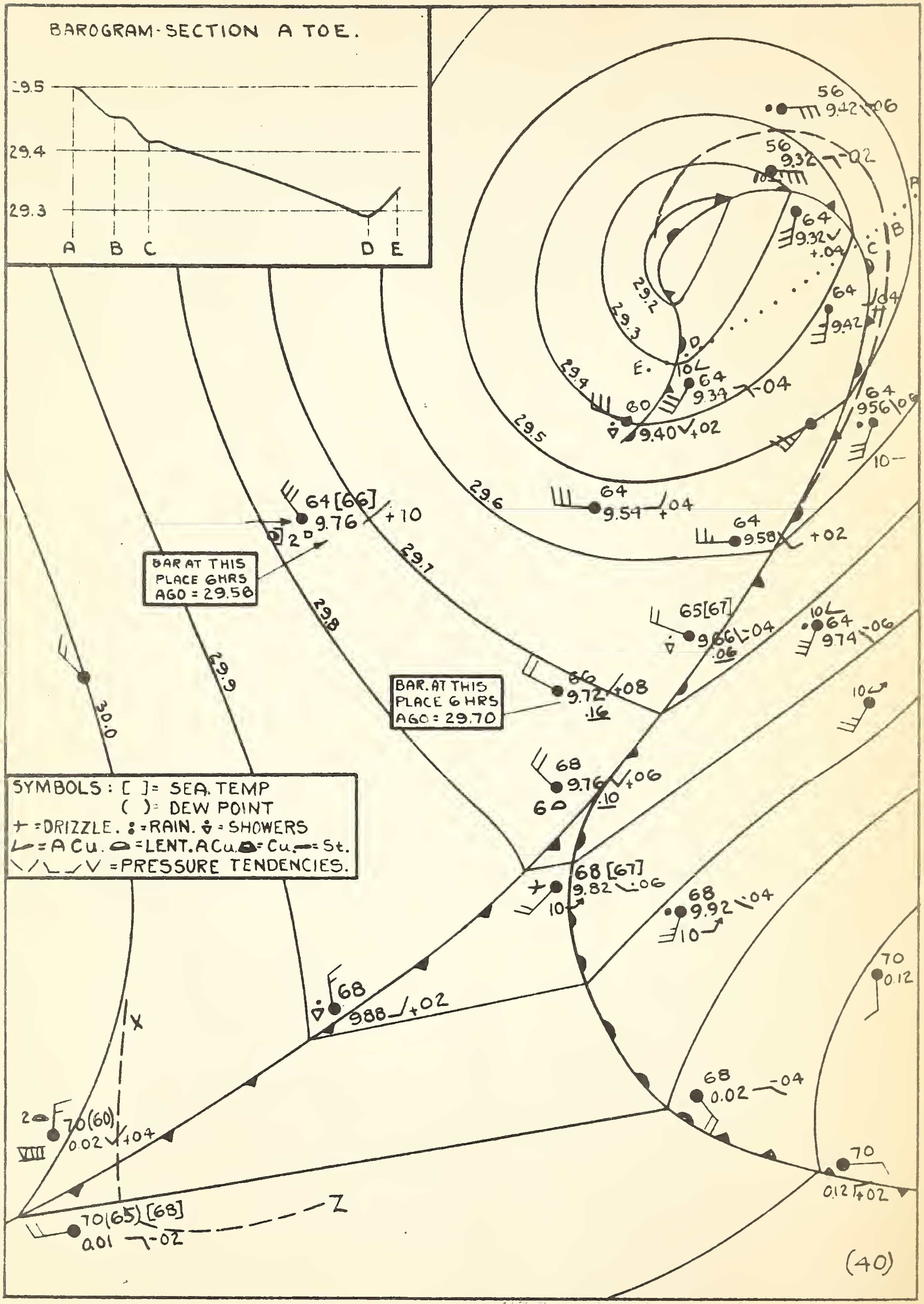
131. At sea where weather reports are scarce, the analysis is used to reveal details of the structure which are often lost when the cyclone is drawn with more or less circular isobars. Figures 38 and 39 in which the weather reports are identical, illustrate this. (Note its forecasting importance). Figure 38 shows isobars drawn from pressure reports without reference to probable frontal structure, indications of which are found in wind and pressure fields, and weather. As is often the case with ocean maps drawn in this manner, some of the winds appear to blow against the gradient (e.g. the 29.5 report, and the 29.42 farther to the left). The wind velocities do not fit the gradient. The rain appears scattered without regular pattern. There seems to be small basis upon which to forecast in detail the character and duration of rain. Figure 39 shows the same cyclone with fronts and isobars drawn to fit the wind, pressure and weather distribution. The guiding principle is that winds and pressure gradient soon reach a "balanced" state. In general, this state probably exists in the well developed storm shown here. Since the reports give vessel observations and the winds are fresh or stronger, they can be taken as representative. It may therefore logically be assumed that winds and gradient here reveal the structure of the cyclone. The reports fit a simple type of occlusion with bent back end, a frequent pattern which is quickly recognized in such a wind and pressure field. Briefly, the central 29.36 with southwest wind and then nearby report of southeast wind with rain (two dots) are probably separated by a front. Similarly, westnorthwest, 29.50 should lie on the western side of the front. These two rain reports which apparently in the same air mass indicate a front warm surface. Therefore the air mass east of the


BAROGRAM-SECTION A TO E.
29.5
29.4
29.3
A
B
C
D
E
BAR AT THIS PLACE 6HRS AGO = 29.58
BAR. AT THIS PLACE 6 HRS AGO = 29.70
SYMBOLS : [ ]= SEA. TEMP
( )= DEW POINT
= DRIZZLE. = RAIN. = SHOWERS
= A Cu. = LENT. A Cu. = Cu. = St.
= PRESSURE TENDENCIES.
29.2
29.3
29.4
29.5
29.6
29.7
29.8
29.9
30.0
X
Z

front is the colder. While evidence is not conclusive as to occluded front structure instead of warm front (lacking information of history, temperatures, etc.), the wind directions and decided V-shape in the isobars indicate occlusion rather than warm front. The V-shape cannot be questioned if wind and pressure fields are drawn to fit reports. The showers (triangle with dot above) reported with pressure 29.60 and the report, partly cloudy, pressure 29.66 indicate that front has passed. The shower at one place and the clearing tendency with northwest wind further confirm the occluded structure. The clearing also agrees with the divergence, and probable subsidence, along the isobar which has anticyclonic curvature in this region. Near the center, the report 29.42 with signs of clearing also agrees with the anticyclonic isobar drawn in conformity with wind and pressure, a structure which naturally develops in this portion of a loop occlusion. The lighter winds here fit the pressure gradient as drawn. The strong northeast winds north of the center, the north wind west of the center and the west wind southwest of the center are in some degree confirmatory of loop occlusion. A crowding of the isobars is to be expected. The increased west wind is common at the tip of such an occlusion. Rain as reported at this point is not unusual, although it is not necessarily proof of such structure. It will be noticed that wind velocities as well as wind directions fit the isobars as drawn in figure 39. For example of similar cyclone over the United States, see map Dec. 31, 1931, 0800. Note clear sky at Springfield, Mo., doubtless due in part to foehn from the Ozarks.

132. Other illustrations of pressure fields indicating the position of fronts when reports are sparse may be found in figures 5, 14 and 40 in which improbable curvature of isobars would result if fronts were drawn otherwise.

133. Figure 40 gives an illustration of some of the principles by which the Bergen school identifies fronts. Beginning in the lower left corner of the figure, the dashed lines x y z indicate how an isobar might be faired past the given pressure readings. Several elements show this to be incorrect and indicate that the trough and front lie between the two stations. The WSW wind and barometer tendency steady then falling indicate approach of a "trough" and therefore a front. Clear sky and hazy, air temperature 70, water temperature (68), and dew point (65) are not inconsistent with warm sector conditions. The nearby report of north wind, with barometer falling then rising indicates passage of the front. The tendency also shows that the isobars must have a definite "Vee". The one fourth cloudy sky, and temperature 70 are not inconsistent with this, considering that the accompanying isobar must have anticyclonic curvature, and that subsidence and lowered humidity are therefore probable. The clouds report two tenths, lenticular altocumulus, the drop in humidity (dew point 60), and visibility VIII


BAROGRAM-SECTION A TO E.
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A B C D E
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= PRESSURE TENDENCIES.
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29.3
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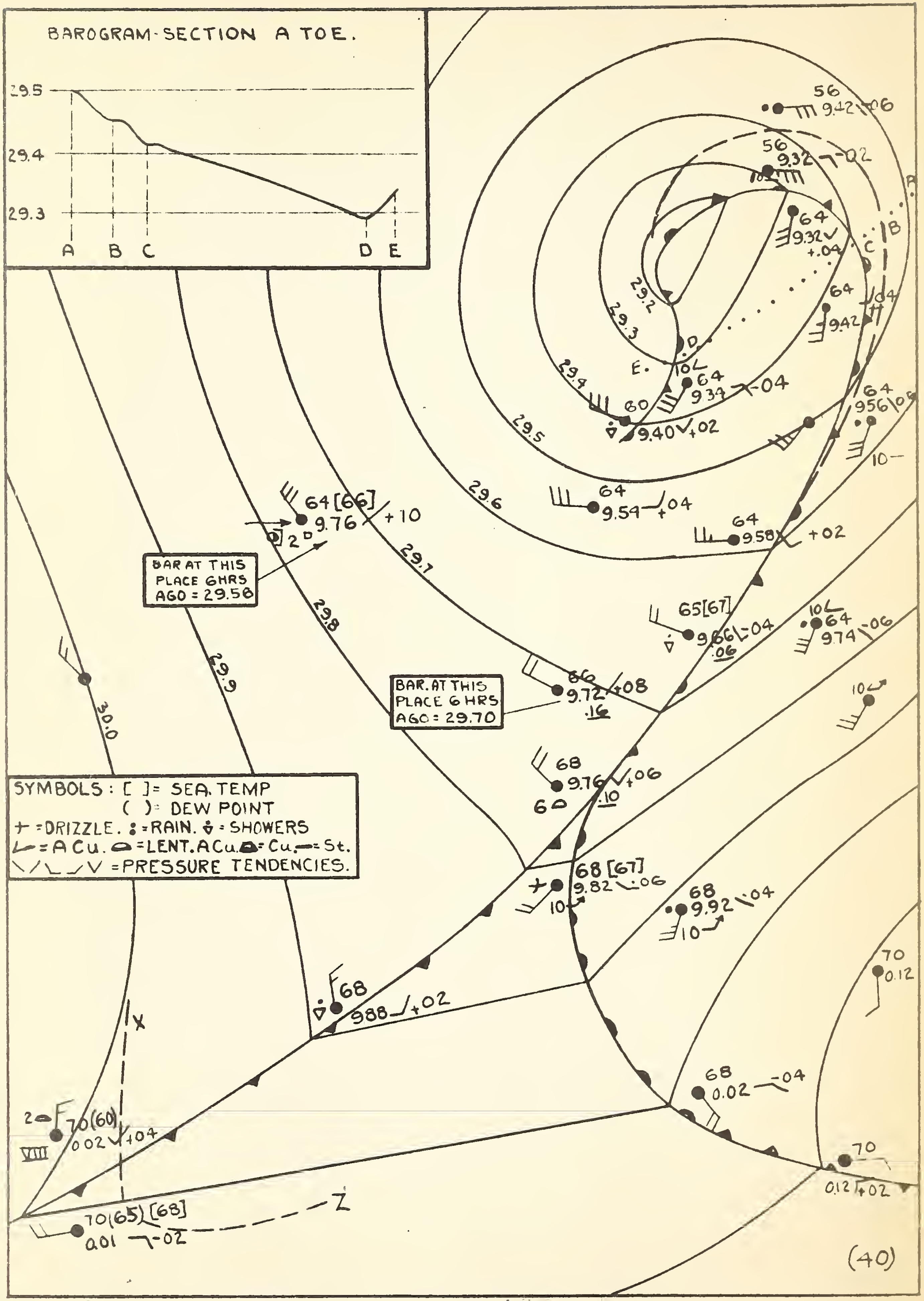
29.6
29.7
29.8
29.9
30.0
X
Z
(40)

(no haze) agree with this and point to air mass different from that at the southern station. The isobars and trough as drawn, explain all of the observed weather conditions. No other general form would explain them. The remainder of the reports to the left of this front and close to it, give evidence that a front has recently passed. The reports show barometer tendencies falling then rising, precipitation in form of showers and cumuliform clouds, good evidence of a nearby front. The wind and temperature reports are not inconsistent with the foregoing, if the front and isobars are as shown. With these more or less confirmatory elements and the almost conclusive evidence of a coincident zone of a falling then rising pressure, there can be little question that a front lies near these stations, its position probably spiraling toward the cyclone center as shown. A study of the sequence from previous maps shows that such a development is probable. Turning to the reports on the right hand front. These are briefly falling pressure tendencies, alto-stratus cloud and rain system lowering into stratus, and general wind and temperature fields indicating a homogeneous air mass different from that to the west. Several elements bear evidence that the front is an occlusion of the warm front type. The form of the pressure and wind fields, the somewhat lower temperature in the air mass on the east side, the absence of temperatures and sky conditions typical of a warm sector, and the alto-stratus system followed abruptly by shower precipitation are evidence of warm front occlusion structure.

134. Near the cyclone center the reports are indicative of an upper front as represented by the dashed line. The evidence is as follows. The history of the occlusion and its warm front character show that an upper front is possible. The pressure and wind fields show that an upper front would advance most rapidly just east of the cyclone center and further south would lie close to the occlusion. The two reports northeast of the center are indicative although not conclusive that an upper front lies between them. The report fartherest north shows by its falling barometer, east wind, and alto-stratus rain that an important front is approaching. The nearby report with wind east, force seven indicates by its steady then falling barometer that a small front may have passed but that the principal front is still approaching from the south or southwest. Winds and temperatures in these two reports seem to belong to one and the same air mass. This confirms upper front structure. The cessation of rain at the second station also agrees. The next report to the south (wind SSW - 6; 29.32 falling, then rising, plus 04) shows that the front has passed and fits with the structure previously found. To the southwest of the cyclone center, a loop occlusion is indicated. Such an occlusion is not unlikely in this portion. The southwest wind, barometer steady then falling and relatively high temperature are evidence of an appraoching front. The nearby west northwest wind, force 6 with barometer falling then rising with showers and


BAROGRAM-SECTION A TO E.
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30.0

colder show that a front has passed, and the sharp change from alto-stratus to showers indicates occlusion. Other reports farther southwest have no signs of nearby fronts, thereby confirming loop occlusion character.

135. The inset in figure 40 shows the typical barograph trace through the upper front, the occlusion and the loop occlusion. At point A, the barometer is falling rapidly as the cyclone center and fronts approach. As the upper fronts passes, the fall ceases for a short time (B) but is resumed as the chief occlusion approaches. With its passage, the fall again stops for a time but is resumed in this case even though the chief front has passed, because the orientation of A-E with respect to position and movement of the cyclone center leads toward still lower pressure. Note however that the resumed fall is at a slower rate thus indicating a different air mass. As the loop occlusion passes (D) the steady rise in the barometer begins.

136. Two reports which show their barometer readings at the previous six hour report, verify the structure as drawn. The one (29.76 rising steadily, plus ten) reported 29.56 six hours before. This is a ship moving eastward. (For brevity, movement in case of other ship reports is omitted here). Since the ship's movement is toward lower pressure, the rise would have been greater if the ship had remained stationary. The fact that its barometer was twenty hundredths lower six hours before and has risen steadily ten hundredths in the last three hours indicates that the rise has been continuous for six hours or more. (An appreciable fall after the reading) of 29.56 would require an improbable rise to reach present reading. The report of past weather shows partly cloudy, no rain last six hours. The clouds have now decreased to two tenths cumulus. All of these elements, pressure change, weather and present sky indicate that no front has passed in the last six hours and aid in verifying the front structure and pressure field as shown. The ocean temperature, (66), two degrees warmer than the air, points to "cold" air mass and may explain the remaining cumuliform clouds. These facts fit the analysis given. The other entry giving the barometer six hours previous shows by similar reasoning that a front has passed within the last few hours. The barometer at present is only .02 higher than six hours ago. Since it has risen .08 in the last three hours it had fallen at least .06 in the preceding three hours. This together with present clear sky, NW force 4 and past rain indicates that a front passed three to six hours before and helps in estimating the position and movement of the front.

137. Farther south a report shows southwest, force four, 10 stratus from southwest with drizzle, and air temperature one degree warmer than ocean, barometer falling then steady, all pointing to warm sector structure with warm front passed within last three hours.

To the southeast a report shows barometer 30.02. The 30.00 isobar must lie near it which necessitates a slight "Vee" concave toward low pressure (as always) in the isobars in that area. This discontinuity together with pressure steady then falling indicates the presence of a front. The above mentioned drizzle report, the haze reported at the station farther south and the general form of pressure and wind fields indicate the existence of the tropical air in form of a warm sector and fix its position approximately as shown. Pressure tendencies and probable shape of isobars are more or less conclusive. Since there is a warm sector, the eastern front is a warm front and the western one, first studied, is a cold front, a fact not certain before because reports are sparse and surface temperatures are inconclusive.

138. The isobars of the warm sector and cold front incidentally illustrate a useful point in forecasting winds following a wind shift. The front lies more nearly parallel to the isobars which precede it (i.e. the gradient is steeper there) showing that the southerly current has a greater velocity than the northwest or northerly current following the front and that the wind will decrease after frontal passage.

139. So far as reports show the general structure is now determined. As drawn, the fronts fit the pressure and wind fields and explain all of the observed facts of clouds, rain, pressure tendencies and temperature. It may be noted that isobars in the warm sector are drawn rather straight and evenly spaced, while isobars which are sharply curved occur only in cold air. These are characteristics agreeing with the usual structure of tropical and polar air currents, respectively. Often what appears to be sharp curvature in a tropical current is due to incorrect location of front. The front position can often be fixed by the position in which it gives smooth and relatively straight isobars in the warm sector.

140. Notwithstanding the fact that pressure tendencies may be complicated by diurnal ranges, etc., they are often conclusive in locating fronts. They also indicate the sharpness of the wind shift. Frequently, the pressure tendencies have an arrangement somewhat as follows. Just east of the front stations reporting falling steadily eight or ten hundredths; just west of the front falling then rising two to four hundredths, and farther west, rising then ten to twelve hundredths. Obviously the front must lie close to the stations reporting falling then rising, the barograph must have shown a sharp reversal in trend. A sharp trough must be drawn to explain these observations. Barometric tendency reports are particularly valuable in tracing fronts as they cross mountainous areas where other surface reports may be less representative. It is important to identify the rapid advance of an occlusion as in the present case because

it is the basis for an accurate forecast of early arrival and passage of showers. For example, on Dec. 13, 1931, identification of an occlusion similar to this permits forecast for Jacksonville as regards approximate time of showers. If the occlusion is incorrectly called a front and the bent back occlusion taken for a cold front, an incorrect forecast results.

The maps listed below were prepared at the Bergen-Oslo institutes as indicated on the maps or in the list. The notes entered on the maps comment on principal features and illustrate the methods described in foregoing paragraphs.

ATTACHED ILLUSTRATIONS:

Figures 1 to 40 (11 pages)
Sample analysis with entry symbols (International)
Vaervarslingen pa Vestlandet, Bergen.

U.S. Map Series 16 to 27 June 1930 (23 maps)
" " " 27 to 31 October 1930 (5 maps)
" " " 19 to 24 January 1931 (N. Pac.) (10 maps)
" " " 29 Jan. to 7 Feb. 1931 (18 Maps) (A.T. series, photostat copies with original of this report only)
" " " 18 to 23 Apr. 1931 (5 maps)
Also the following which were partially analyzed in Bergen, and completed in BuAero (WML & FWR - Jan. 1931): -
U.S.Map Series 12 to 16 July 1930 (10 maps transcribed from A. T. series)
U.S.Map Series 18 to 21 Nov. 1930 (5 maps)
" " " 5 to 9 March 1931 (8 maps)
" " " 30 Mar. to 3 Apr. 1931 (8 maps)(included tentatively)
" " " 4 to 8 Apr. 1931 (5 maps)

F. W. Reichelderfer.